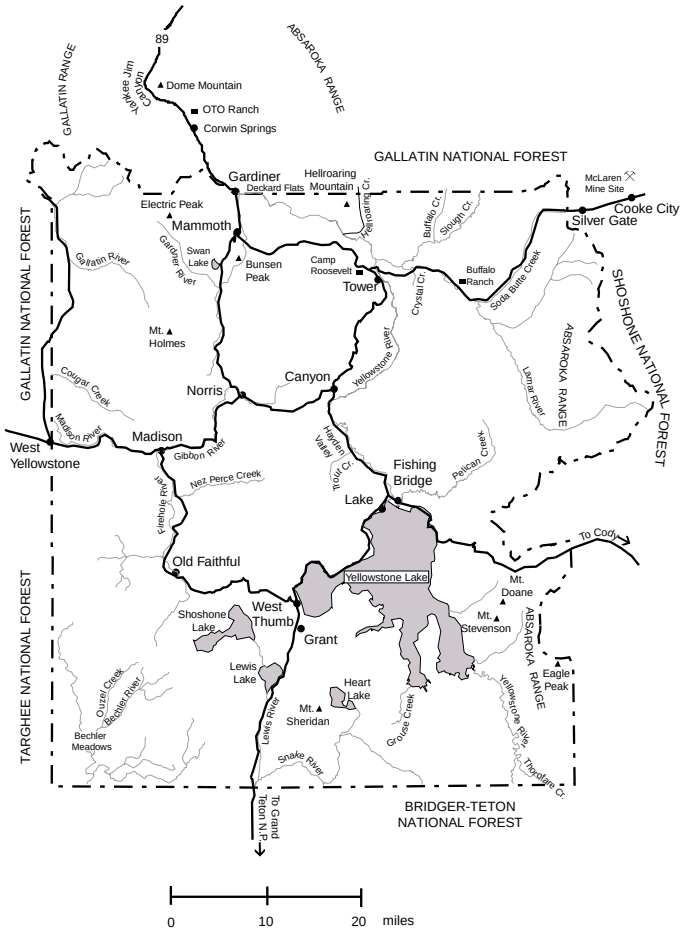
1997-1998
Investigators' Annual Reports

Yellowstone National Park

YELLOWSTONE NATIONAL PARK



Yellowstone Center for Resources
P.O. Box 168
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Cover: Yellowstone sand verbena *(Abronia ammophila)*, endemic to Yellowstone National Park, was known only to exist along a two-mile stretch of Yellowstone Lake shoreline. After comprehensive surveys in 1998, researchers found three additional sites and documented at least 8,325 individual plants. Photo: Jennifer Whipple

Acknowledgments: The National Park Service thanks the researchers that have contributed vastly to our understanding and knowledge of this special place. The compilation and editing of this report was done by Kevin Schneider and Ann Deutch.

FOREWORD

The first formal scientific studies in Yellowstone began with a rudimentary microscope, a rucksack, and perhaps a crude map of the area. Today, researchers armed with GPS units, electron microscopes, lap top computers, and all of technology's latest marvels, continue to follow their predecessors in searching for a deeper understanding of this special place. Nonetheless, after nearly 130 years of careful study, much remains for us to learn.

Even at Old Faithful, perhaps the most studied geyser in the world, scientists search for answers to the mysteries of this subterranean plumbing system. And yet, the National Park Service can not truly protect these resources without a solid, scientific understanding of them. How do we really know if geothermal development five miles, or even fifty miles from Yellowstone's borders will not upset Old Faithful's faithfulness?

The National Park Service depends upon researchers and scientists to help preserve Yellowstone for the future. No longer perceived merely as scenic vacation spots, we now know that parks are central to protecting ecosystem health. The new, service-wide Natural Resource Challenge reflects this mandate, and moves the National Park Service beyond scenery management. This effort, involving universities, nonprofit organizations, private corporations, and other agencies, will revitalize natural resource management in the national parks. The Natural Resource Challenge recognizes that combating the variety of threats parks face today – habitat destruction, air and water pollution, and external development – requires active and informed park management to a degree unimaginable when Yellowstone was first established in 1872.

Research has forced us to re-evaluate past management practices in Yellowstone. What seemingly appropriate actions today will become tomorrow's tragedies? What futuristic Yellowstone discoveries will revolutionize our world views, or improve medicine? These questions will undoubtedly persist, but one thing is certain: Yellowstone's cadre of researchers, like those before them, will help the National Park Service make decisions grounded in sound science, and not speculation, ensuring that Old Faithful continues to inspire Americans for many years to come.

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AQUATIC STUDIES

Title: **Interaction of Parasites for Cutthroat trout and Lake Trout in Yellowstone Lake, Yellowstone National Park**

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Objectives: Determine the parasites present in the two salmonid species in Yellowstone Lake, Yellowstone National Park, and the variation in parasite numbers. Determine if there are common parasites for the two salmonid species as well as those that are host specific. Do DNA analysis on the parasites. Correlate lake trout parasites for fishes from Yellowstone Lake and those in Heart and Lewis Lakes.

Findings: A total of 101 native Yellowstone cutthroat trout, *Oncorhynchus clarki bouvieris*, 27 introduced lake trout, *Salvelinus namaycushs*, and 40 introduced longnose sucker, *Catostomus catostomuss*, from Yellowstone Lake were examined for eye flukes in 1997. Metacercariae of a trematode fluke *Diplostomums* were in vitreous humor and/or lens of 94% of the Yellowstone cutthroat trout, 92% of the lake trout, and 78% of the longnose suckers. Longnose suckers had 7% prevalence of infections in both the lens and vitreous humor of metacercariae, while Yellowstone cutthroat trout had 3% and lake trout had 8%. *Diplostomum spathaceums* was in lens tissue of 5% of infected Yellowstone cutthroat trout and 93% of the longnose suckers, and *Diplostomum baeris* was in vitreous humor of 92% each of infected Yellowstone cutthroat trout and lake trout. Morphological characteristics indicate that a single species infected the lens of Yellowstone cutthroat trout and longnose sucker, while another species infected lake trout. Impacts of the parasite interchange between native and introduced fishes of Yellowstone Lake are unknown but should be monitored each year.

Title: **Reference Stream Monitoring - Long Term Trend Sites**

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Additional Investigators: Mr. Mark Rogaczewski

Objectives: Collection of long term monitoring data for water quality, macroinvertebrates, and habitat at least impacted reference stream sites in Yellowstone National Park.

Findings: Bioassessments at streams throughout Yellowstone National Park. Bioassessments include 12 water chemistry parameters, 13 habitat assessment parameters, and macroinvertebrates from eight modified surber samples. This data is available digitally from the principal investigator.

Title: **The Biogeochemistry of Sublacustrine Geothermal Vents in Yellowstone Lake, Wyoming**

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Objectives: Yellowstone Lake is an ecosystem in which closely linked components of microbiology, geochemistry, and mineral reactivity justify the term "Biogeochemical Cycling". The overall objective is to develop quantitative understanding leading to a biogeochemical flux and mass balance model for hydrothermal vent systems. More specific objectives are as follows:

A.) To determine the importance of vent and fumarole emanations relative to shallow groundwater and sediment-water flux in enrichment of major ions of Yellowstone Lake water; B.) To identify short (hours-days) and long-term (annual) variability in submarine vent activity; C.) To assess the potential

geochemical interactions with iron during formation of iron oxides formed via vent fluid interactions with cold lake water; D.) To determine the relative importance of abiotic sulfur oxidation and microbially-mediated sulfur oxidation; E.) To determine the specific contributions of photosynthetic, heterotrophic, and chemolithotrophic biomass production; F.) To analyze transformations of sulfur by measuring the stable isotope composition of mineral, organic matter, and micro- and macroorganisms; G.) To utilize trace metal concentrations in aqueous and solid phases to evaluate hydrothermal activity and geochemical processes participating in elemental cycling; H.) To estimate the quantitative impact of sublacustrine hydrothermal vents and springs on the biogeochemical mass balance for the lake.

These efforts are intended to lead to a significant quantitative improvement in understanding of biogeochemical dynamics for select parameters. Control of nutrient and trace element cycling involves physical transport (e.g., riverine inflow and outflow, sediment-water flux, hydrothermal venting, groundwater inflow and outflow, mixing), chemical transformation (e.g., sorption by minerals precipitated from vent fluids, precipitation and dissolution, oxidation-reduction transformations), and biological interactions (e.g., assimilation into biomass, energy-yielding oxidation-reduction transformations, organic matter diagenesis). This work will provide background necessary to begin modeling basin-wide fluxes of biogeochemical important elements to elucidate the contribution of geothermally altered groundwaters to Yellowstone Lake.

Findings: Several interesting and unique sublacustrine hydrothermal areas were discovered, explored, and sampled in the following areas of the lake: at least three distinct regions in West Thumb, off Stevenson Island, in Mary Bay, in Sedge Bay, and off Storm Point. In addition, some relict hydrothermal features have been identified in Bridge Bay. Future plans include a precision bathymetric survey of the northern part of the lake to assist in the elucidation and discovery of other geothermally active regions of the bottom.

Title: **Heavy Metals in Soda Butte Creek**

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Objectives: This study: 1.) documents the distribution of trace metals in stream bed sediments of Soda Butte Creek at spatial scales ranging from 30 cm to 30 km and temporal scales ranging from 2 hours to 6 years; 2.) examines the processes causing variations in these distributions; and 3.) determines the links between trace metal concentrations and biotic health in the riparian zone.

Findings: Trace metal concentrations in the stream bed generally decrease in the downstream direction as a function of dilution mixing with clean sediments from tributaries. Local scale metal variations in riffles, pools, and bars vary as a function of sediment size and perhaps as a function of residence time and resultant accumulation of iron oxides. Biodiversity within the stream improves within the downstream direction, but has shown little improvement over the last 50 years. In contrast, some biotic impacts in the floodplain 20 km downstream are as severe as those at the tailing site. The amount of impacted area in the floodplain, however, is slowly improving over time as contaminated sediments are removed by floods.

Title: **Rainbow Trout Tolerance of Elevated Boron Concentrations in the Firehole River**

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Objectives: 1.) Review historical data related to the trout fishery, routine water quality parameters, and boron concentrations in the Firehole River. 2.) Sample Firehole River water in May, to analyze for routine water quality parameters and concentrations of boron.

Findings: We prepared a report (Meyer et al. 1996) about 1.) the history and current status of the rainbow trout fishery; and 2.) the historical database for water chemistry and physical habitat in the Firehole River (FHR) in Yellowstone National Park (YNP), Wyoming. In addition to conducting our own literature searches, we relied extensively on publications, reports, and data stored at YNP headquarters in Mammoth, Wyoming.

The rainbow trout (RBT) fishery in the FHR is unique, because the population effectively is closed to immigration by physical barriers on the downstream end (Firehole Falls and Cascades of the Firehole). Moreover, the population is contained within the relatively shallow-gradient stretch of the FHR along the Lower, Midway, and Upper Geyser Basins by a physical barrier upstream of the Upper Geyser Basin (Kepler Cascades). Due to thermal inputs from the geyser basins, this stretch of the FHR contains relatively warm and highly mineralized water.

Because RBT have not been stocked in the FHR since 1955, the population is self-sustaining. However, during summer large numbers of RBT migrate out of the mainstem FHR and into cooler-water

tributaries, ostensibly because water in the FHR warms to potentially lethal temperatures (up to 30 degrees C).

Concentrations of boron (input mainly from geothermal sources in the geyser basins) also increase as flow in the FHR decreases during summer. Thus, avoidance of elevated boron concentrations (or a combination of boron and other dissolved constituents and temperature) cannot be rejected as an explanation for RBT migration out of the mainstem FHR. However, for the following two reasons we conclude that elevated boron concentrations alone cannot be responsible for the RBT migration in summer. First, limited historical data suggest boron concentrations in the FHR are even higher in fall and winter (when female RBT undergo oogenesis, adults spawn, and eggs are incubating in the gravel redds) than they are during the warm water period in summer. Second, our statistical analyses of historical water quality data indicated a high correlation between boron concentration and conductivity of the water (a parameter measured much more often than boron concentration). Using historical conductivities and flow measurments, we estimated that boron concentrations in the Lower Geyser Basin reach of the FHR likely are about 0.8 to 0.9 mg/l during the RBT egg maturation period in fall and about 0.9 to 1.0 mg/l during the spawning and embryo development periods in late fall and winter (compared to about 0.6 to 0.8 mg/l during summer).

Insufficient information is available to determine if successful recruitment of RBT occurs in those high boron concentrations in the mainstem FHR, or if the majority of the recruitment in the population comes from tributaries that have lower boron concentrations.

As part of this project, we also collected water samples from the FHR and several tributaries on May 15, 1996. Although we had hoped to analyze pre-runoff concentrations of boron, warm weather and rain beginning a few days before our sampling trip initiated high spring runoff. Thus, our chemical analyses are representative of dilute conditions, rather than highly concentrated late-winter conditions. We sampled water at the following five stations: 1.) FHR, about 250 m upstream from Grand Loop Road bridge (downstream from Kepler Cascades); 2.) Iron Spring Creek, about 1 km upstream from Little Firehole River; 3.) Little Firehole River, about 200 m upstream from confluence with Iron Spring Creek; 4.) Firehole River, about 200 m downstream from Biscuit Basin foot bridge; 5.) Nez Perce Creek, at Grand Loop Road bridge. Temperature, pH, conductivity, alkalinity, calcium, potassium, magnesium, sodium, chloride, sulfate, fluoride, and boron at those five sites are listed in Table A-11 in Meyer et al. (1996).

Title: **Sources of Phosphate in the Headwaters of the Snake and Heart Rivers**

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Additional Investigators: S. Dustin

Objectives: Conduct trophic state water quality research on lakes.

Findings: Water was collected on September 9, 1998. One sample from the north shore of Shoshone Lake had chlorophyll-A of 1.1 mg/l, secchi depth of 4-5 m, total phosphorus 0.036 mg/l. One sample from near the outlet of Lewis Lake had chlorophyll-A of 1.3 mg/l, secchi depth of 4-5 m, total phosphorus 0.02 mg/l.

Title: **Study of the Effects of the 1988 Wildfire on Yellowstone Stream Ecosystems**

Principal Investigator: Dr. G. Minshall

See Ecology

Title: **Hydrogeomorphic Approach to the Assessment of Wetlands in Yellowstone National Park**

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Objectives: Collect data in six to ten depressional wetlands in Yellowstone National Park. This data will

be added to an existing database from Ninepipes National Wildlife Refuge and the Bandy Ranch. We are collecting data in the park due to lack of human disturbance and the probability that the wetlands sampled will remain in an undisturbed condition for reference purposes.

Findings: We have completed 10 percent of the data collection planned. We plan to be able to complete data collection in July of 1999.

Title: **Yellowstone River Basin - National Water Quality Assessment (NAWQA)**

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Objectives: The overall goals of the NAWQA Program are to 1.) describe current water-quality conditions for a large part of the Nation's freshwater streams and aquifers; 2.) describe how water quality is changing over time; and 3.) improve our understanding of the primary natural and human factors affecting water quality.

Findings: Samples were collected at several sites for bed sediment and fish tissue analysis. The samples were sent to the USGS National Water Quality Laboratory for processing. They will be analyzed for trace elements and organics.

Title: **Effects of Depleted Amphibian Populations on the Community Ecology of Alpine Ponds**

Principal Investigator: Dr. Wendy Roberts

See Ecology

Title: **Diatoms in Yellowstone National Park**

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Objectives: 1.) Determine rate of evolution of diatom endemic to Yellowstone Lake. 2.) Determine modern climate, limnological, and landscape processes affecting modern diatom distribution. 3.) Use fossil records of major lakes to reconstruct ecosystem past.

Findings: 1.) *Stephanodiscus yellowstonesis* evolved in Yellowstone Lake in a thousand year period (ca. 11,500 ybp > 10,500 ybp) 2.) Main determinant of diatom distributions is winter precipitation. The system is N-limited in drought years; N-replete in wet.

Title: **Upper Henrys Fork Watershed Stream Habitat Assessment**

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Additional Investigators: Jim Gregory

Objectives: 1.) Collect physical, chemical, and biological data on stream habitat conditions. 2.) Determine presence/absence and relative abundance of native salmonids

Findings: Thirty-seven stream reaches in the upper Henrys Fork watershed were surveyed in 1997. These included reaches on Robinson, Little Robinson, Wyoming, and Rock creeks that lie at least partially in Yellowstone National Park. Most surveyed reaches were impacted very little by human activity. Study streams were generally characterized by volcanic geology, low gradient, and fine substrate. Aquatic invertebrates were abundant in most streams, and invertebrate diversity was high. Invertebrate communities in the Yellowstone Park streams were dominated by water beetles and midges. Brook and rainbow trout were found in most reaches surveyed. Brown trout occurred in Warm River and Robinson Creek. Yellowstone cutthroat trout were observed in Robinson and Wyoming creeks.

Cutthroat trout were not observed in Robinson Creek above a barrier falls in Yellowstone National Park where they had been observed in a 1983 survey. Cutthroat were not observed in Rock, Snow, Fish, and Little Robinson creeks, which contained cutthroat in 1983.

Title: **Effects of Geothermal Additions on the Biology and Distribution of Trout in the Firehole River, Yellowstone National Park.**

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Objectives: Determine the extent that trout in the Firehole River reside in areas of high mineral concentrations and how this affects their distribution, behavior, and reproduction. This will be accomplished by performing a detailed study of the water quality and the trout population in the middle segment of the Firehole River.

Findings: Population surveys showed an increase in fish densities in the lower Firehole River (FHR) and Fairy Creek (FC) sites as water temperatures decreased in the late fall. Spawning runs were identified in the main stem of the Firehole River (FHR) and tributaries from November 1997 through January 1998. Abundant spawning redds were located in the highly mineralized waters in the lower FHR and in FC. Results from the water quality surveys have shown that FC had the highest mineral concentrations among all sites sampled in the FHR drainage. Spawning and large aggregations of fish observed in FC and the lower FHR indicate that the thermal/productivity preference by fish may override an avoidance response to the high mineral concentrations. Concentrations of arsenic (As) in FC and the lower FHR during 1997 were consistently observed above 350 ppb, exceeding the EPA Quality Criteria for Water (1987).

Analyses of chemical and fish distribution data are currently being conducted. A final report on the project should be completed during 1999, with publications expected in Transaction of the American Fisheries Society and/or the Archives of Environmental Toxicology and Contaminants. Locations of spawning in the Firehole River are being mapped using GIS and will be made available to the National Park Service when complete.

ARCHEOLOGY

Title: **Archeological Investigations in Yellowstone National Park-Various Projects**

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Objectives: To salvage vertebrate carcasses for creating a comparative skeleton collection. This comparative collection will be used in the identification of archeologically derived faunal material.

Findings: Archeological sites along the Yellowstone River have produced the first evidence of fishing for the region. Faunal remains from various sites in the park indicate that all large mammals were present prior to Euroamerican contact. However, studies are ongoing to determine the prehistoric ecology and biogeography of these species.

Title: **Geochemical Investigations of Obsidian Source Material**

Objectives: Obsidian, a natural volcanic glass, was widely used by prehistoric groups throughout the Intermountain West to manufacture tools. Each obsidian source has its own unique chemical composition consisting of different amounts of various constituent elements. The concentration of these elements can be measured, providing a quantitative "signature" for each obsidian source. Once the geologic sources in the region been chemically characterized, obsidian artifacts can then be analyzed and their chemical profiles matched to known geologic sources. The spatial and temporal changes in obsidian artifact distributions provide archeologists with a powerful tool for reconstructing the lifeways, trading patterns, and settlement systems of the region's aboriginal populations.

Findings: Prior to the beginning of this project, only three geochemical sources were documented as having been utilized by groups in Yellowstone. Our studies have identified at least 10 different sources of obsidian that were used to manufacture tools. Some of these sources are over 200 km from the park and provide a much more dynamic view prehistoric land use and toolstone procurement than previous studies. Our studies have included curated materials from the Mammoth Museum that were collected by visitors and park employees over the years, as well as from professional research projects.

Title: **Yellowstone Archeological Project**

Objectives: To collect various economic plant species for the development of a comparative collection that can be used as a reference for archeologically derived plant remains.

Findings: This is an ongoing project for comparative purposes. The specimens collected were used in comparing archeological materials from prehistoric cooking hearths along the Yellowstone River and Yellowstone Lake between 1991 and 1994. No further work has been conducted.

Title: **Archeological Research along the Yellowstone River and Miscellaneous Archeological Research in Yellowstone National Park**

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Objectives: Investigations into the prehistoric cultural history and adaptations in Yellowstone National Park will be combined with those in the surrounding Greater Yellowstone Area to gain a larger and more accurate view of early times in the region. This broad project will combine results from compliance driven investigations with research investigations in a multi-year study.

Data to be collected include radiocarbon and obsidian hydration dates, diagnostic artifacts including projectile points and pottery, floral and faunal materials, pollen, and chemical sourcing of obsidians. All collections will be stored at the museum in Mammoth Hot Springs.

About half the work was compliance driven for ground disturbing projects. These included inventories along existing highways for the proposed Federal Highway Administration rehabilitation of the road system. Other compliance projects were for backcountry trails rehabilitation. Road segments included Mammoth to Gardiner – both the existing road and high road, and the east side of the highway between Canyon and Fishing Bridge. Inventoried areas on backcountry trails were spread broadly around the park including Fan Creek, Bighorn Creek, Big Game Ridge, Fox Park, Bliss Pass, and Bunsen Peak. Research driven inventory covered the Yellowstone River between Fishing Bridge and Canyon Village.

Findings: Five sites tested during 1997 were severely damaged by flooding in the two prior years. It is hypothesized that sites in this part of the Yellowstone River were winter camps and that people could

have hunted bighorn sheep in the vicinity. Four Yellowstone Institute classes and other volunteers greatly assisted with the fieldwork.

A buried, multi-component site along the Gardner River was tested for the National Register under the Federal Highways Program. The goal of this particular work was to determine what part of the site was within the current highway right-of-way. The core of the site appears to be out of the right-of-way. However, cultural deposits and features (hearths) do occur within the area of particular interest.

A site was studied on an intermittent unnamed tributary of the Yellowstone River where the drainage is undergoing severe downcutting and sidewall cutting, resulting in exposure of and damage to prehistoric campsites on both sides. A Pelican Lake projectile point collected from the surface dates from c. A.D. 200-1000 B.C. The prehistoric component is assumed to represent the same or similar peoples camping in this location during a short period of time. The cultural material includes chipped stone and flaking debris from several raw materials, discrete fire-cracked rock concentrations filled with charcoal, and a 5-10 cm. ashy soil horizon. Some archeological large mammal and bison bone was collected. The horizontal extent of these cultural remains are away from the drainage where they are still covered with slopewash.

Another site located on a small drainage where colluvium had buried a multi-component site was reported by Jim Sweeney, who observed roasting pits eroding into the Yellowstone River. We salvaged three roasting pits and then gathered data from the small area of remaining site.

At another site, deeply buried, fire-cracked rock unit was sampled about 10 m east of an earlier test by the Midwest Archeological Center (Ken Cannon), but no diagnostic material was found.

The largest and most important site studied this year extends along bank of the Yellowstone River for more than 100 meters. There are three buried components: The highest (youngest), dated at 630+/-70 BP (Beta-108594) [Unit 1] and 930+/-60 BP [Unit 9], contained prehistoric pottery that was identified as Intermountain Ware, which is believed to represent prehistoric Shoshone people and is the second find of this kind of pottery in the park. (The other Intermountain Ware was found on Yellowstone Lake.) The second component represents Pelican Lake culture and the third did not have any diagnostic artifacts. Results of the faunal identifications may show which animals people were eating and possibly which season the camp was used. Data from obsidian sourcing, pollen, charcoal identification, macrofloral analyses, and more radiocarbon dates are not yet available but will be incorporated into the annual descriptive report for the 1997 field season.

Under the National Register testing, it was determined that these sites represented tool manufacturing, with obsidian composing more than 99% of the raw material. For sites close to Obsidian Cliff, the Obsidian Cliff plateau is the most likely source of raw material; for sites farther away, it is likely that at least some obsidian was obtained in the form of cobbles from the glacial and river gravels. All sites appeared to have good integrity and are recommended as National Register eligible.

For the Yellowstone River and some of its tributaries, 1,308 acres were intensively inventoried using a

subjectively selected sample of landforms. Documentation was made of 33 new sites and 13 previously recorded sites that contain small to large lithic scatters, often with fire-cracked rock features; some contain tipi rings or stone circles. The sites yielded debitage, projectile points, scrapers, bifaces, drills, and other artifacts. Faunal material, especially bison remains, are fairly common on some sites. Unauthorized collection of artifacts was documented on one site and suspected on another.

In 1998, one site was tested in the Black Canyon of the Yellowstone upstream from Gardiner. Testing revealed five components sealed by overbank flood deposits. This site is much like the one across the river in that it is of very high value with intact features, good stratigraphy, and excellent faunal preservation. Macrofloral samples were sent for analysis but the results have not yet been received. An exciting new development in 1998 was the recognition of a new source for archeological obsidian. This is on the east shore of Yellowstone Lake. After we recognized this obsidian was used by early people for tools, we went back to obsidian specimens from unknown sources. There we were able to identify about half of the 17 unknowns from a site on the north shore of Yellowstone Lake as coming from the east shore obsidian source. It would be important to identify boundaries and exposures for the east shore obsidian source. For all 1998 fieldwork, 296 new prehistoric sites were recorded and 26 previously known sites were documented to current standards. Collected materials will be stored at the museum in Mammoth Hot Springs.

Title: **Parkwide Road Improvement Inventory and Testing**

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Objectives: In 1997, Class III cultural resource inventory of portions of the Grand Loop Road south of Bridge Bay, test excavations, and additional archaeological investigations at 10 prehistoric sites throughout the park. In 1998, archaeological test excavations at prehistoric and historic sites located in the northeastern corner of Yellowstone National Park and Canyon to Lake Junction Road as well as data recovery and mitigation along the Madison to Norris Road.

Findings: In 1997, buried cultural materials were found at all 10 sites. These consisted of chipped stone tools and debitage, mostly made from obsidian. Of the 31 obsidian artifacts that were submitted for source analysis, 30 were identified as coming from Obsidian Cliff. The other came from Lava Creek welded tuff, also a local source.

One of the sites contained three rock cairns that were test excavated. Except for a few flakes, no other cultural materials were found in the cairns. Seven other sites, located to the north and south of Obsidian Cliff, appear to be lithic workshops for the manufacture of obsidian tools. A site situated in Lamar Canyon that consists of a sparse scatter of chipped tools and debitage (mostly local cherts) while the last investigated site was found to be an extension of the Fishing Bridge site, on the north side of Yellowstone Lake.

Our investigation found diagnostic artifacts representing temporal periods ranging from late Paleoindian to Late Prehistoric. However, intact buried cultural levels could not be defined, probably due to past bioturbation. Most of the cultural materials were located within the upper 10-30 cm. No features or faunal remains were located except for a few intrusive rodent bones. Site eligibility and significance is still being evaluated, but most of the investigated sites will probably be considered ineligible because of their lack of integrity.

During 1998, in the northeastern corner of Yellowstone, test excavations were conducted at three prehistoric sites. Buried cultural materials were recovered from all three sites but buried cultural levels were only encountered at two sites. The buried level at one site consisted of a small (ca. less than 5 m diameter) concentration of debitage and a few chipped stone tools and burned and unburned faunal remains. The faunal remains were identified as elk, one of which provided an AMS radiocarbon date of 80+/-50 B.P.. Calibration of this date indicates a probable Historic/ Protohistoric occupation. Another site yielded a Late Archaic occupation, dated at 1940+/-50 B.P., that contained a large corner-notched hafted knife, pestle, end scraper, other chipped stone flaking debris, and a few faunal remains associated with a small basin-shaped hearth feature and burned rock level. Two of these sites are eligible for listing on the National Register of Historic Places.

During 1998, from Canyon to Lake Junction, 13 archeological sites were recorded during the cultural resource inventory, five of which were previously recorded. All of these were prehistoric scatter of chipped stone tools and flaking debris, except for a site near the Mud Volcano which also contained the remains of a collapsed historic cabin and the Grand Loop Road (an historic district). Abandoned segments of this road were identified during the inventory. Another aspect of the project included test excavations at a site located south of Canyon. Buried stratified prehistoric occupations were identified, one probable Late Prehistoric/Late Archaic age component, and another lower component that is radiocarbon dated as Middle Archaic in age (ca. 4380 years B.P.). Large quantities of obsidian debitage and chipped stone tools were identified, suggesting a campsite function to the site.

Along the Madison to Norris road, excavations were conducted which contained historic and prehistoric components, located on a relatively flat terrace along the Gibbon River. The prehistoric component contained obsidian debitage, but was undated. The historic component is the main focus of the excavation, and documents the historic remains of a 1928 road construction camp. The excavations also revealed cultural materials associated with an earlier Shaw and Powell lunch station during the early 1900s and a later 1931 road construction camp. Historic materials included bottles, cans, ceramics, bone, and other items.

Artifacts located during these investigations were collected and will be curated at the park's Branch of Cultural Resources in Mammoth.

Title: **Analysis of Obsidian in the Northwestern USA**

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Additional Investigator: Craig E. Skinner

Objectives: The major objective of this research is to establish a geochemical database of obsidian sources in the northwestern USA, including sources in Yellowstone National Park and adjoining areas. Samples of obsidian from various source areas are collected and analyzed by two analytical techniques (neutron activation analysis and x-ray fluorescence analysis) to establish the database. In addition, the source samples are being collected from primary outcrops and secondary deposits to establish the true availability of each obsidian source group to prehistoric peoples. The geographic coordinates of each sample are being entered into the database along with the chemical analysis information.

Findings: To date, three major homogeneous geochemical sources have been fully characterized in Yellowstone National Park - Obsidian Cliff, Cougar Creek, and Gibbon River - following a collection visit to Yellowstone National Park in September 1998. Two other geochemical groups on the Gibbon River are also known. Samples from one of the Gibbon River sources were collected in 1998 and proven to be of poor quality and probably of little importance archeologically. The Dunraven Pass samples were not collected by these researchers but given to one of us by a collector. Unfortunately, we were unaware of this outcrop during our visit to Yellowstone in 1998. We do not know if Dunraven Pass obsidian was important archeologically and will keep this question in mind as we continue our research.

Title: **A Petrological and Geochemical Analysis of the Tanker Curve Obsidian**

Principal Investigator: David Hansen
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Omaha, NE 68124

Objectives: To Correlate the Tanker Curve obsidian deposit, which is of a secondary origin, with its parent body.

Findings: The study is finished as of December 1997. Tanker Curve most closely correlates with the Gibbons River obsidian deposit.

Title: **Historic Site Investigations: FHWA Projects**

Principal Investigator: Kenneth Karsmizki
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Objectives: Topics of archival research during 1997 included Fountain Soldier Station, Hobart Hotel, Wiley Swan Lake Camp, Lamar Valley Buffalo Ranch, Soda Butte Soldier Station, and Tower Soldier Station. Sources included: the National Archives in Washington, D.C. and College Park, Maryland; Yellowstone National Park archives in Mammoth, Wyoming; Special Collections at Renne Library, Montana State University, Bozeman; the Livingston Public Library, Livingston, Montana; and the Montana Historical Society in Helena.

Archaeological testing in 1997 was limited to the Soda Butte Soldier Station, where a magnetic survey was conducted over 0.4 acres of the site to test the subsurface archeological resources within a 20 m x 80 m area centered in the site previously surface collected. In addition to being non-intrusive, the magnetic survey provides electronic data and hard copy maps that can be used in further archeological research. The Tower Soldier Station was subject to archaeological testing in 1998.

Findings: The 1997 magnetic survey identified sites of concentrated sheet refuse located on the historic surface of the site and anomalies within the site's core, of which three areas were tested further by limited excavations. As expected based on the magnetic data, the excavations showed that one area was a building site, one was a privy location, and the third a trash deposit. The subsurface archeological

resources have good integrity and offer opportunities for further research and interpretation of military occupation of the site. It is also known that once the military departed, the site was used as a ranger station.

During the fall of 1998 the Museum's crew visited the Tower Soldier Station site and conducted three operations. The first was a systematic intensive surface collection of an area within which was found the sites of several buildings believed to be associated with the Tower Soldier Station. The surface collection was followed by a geophysical survey of the same area using proton magnetometers. Finally, the crew completed four archaeological test excavations, the locations of which were based on observations of depressions or, in one case, the results of the geophysical survey. A total of 2,720 artifacts were recovered during the course of the surface collection. This material has been processed and computerized. The report is presently being prepared for the Tower Soldier Station project.

Title: **Obsidian Studies: XRF Characterization of Obsidian Sources of Yellowstone National Park**

Principal Investigator:	Dr. Raymond Kunselman
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Objectives: Characterizing obsidian sources for chemical composition using XRF to match prehistoric artifacts to their obsidian source. Yellowstone obsidian has ended up in prehistoric sites in Iowa, Colorado, Wyoming, and several other states.

Findings: The main Yellowstone source was Obsidian Cliff, and prehistoric obsidian artifacts ended up in many states. The amount that was procured directly and the amount traded down the line has not been determined, and this determination of kinds of contact is active.

BOTANY

Title: **Vascular Flora of the Greater Yellowstone Area**

Principal Investigator: Mr. Erwin Evert
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Objectives: 1.) To collect vascular plant specimens as vouchers for distribution maps to be included in the investigator's flora of the Greater Yellowstone Area. 2.) To collect specimens of species that have not been vouchered for Yellowstone National Park (YNP) but have been reported for YNP. 3.) To find and collect vascular plant species that have not been reported for YNP. 4.) To produce a complete up-to-date flora of YNP and surrounding region.

Findings: *Thalictrum alpinum* L., Alpine Meadowrue, was collected (E. Evert 35826, July 17, 1998) from Swan Lake Flat at the edge of a swale where a small population occurs. This species previously unreported for YNP is known to occur at only four other locations in the Greater Yellowstone Area. Specimens are to be deposited at the Yellowstone Herbarium and the Rocky Mountain Herbarium, University of Wyoming.

Title: **Pest Trend Permanent Plots for White Pine Rust**

Principal Investigator: Ms. Jeri Lyn Harris
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Objectives: Long term monitoring of three plots on the eastern side of the Absaroka Mountains for white pine blister rust disease.

Findings: Plots were installed near Eleanor Lake, T52N. R110W. Sec.18. Disease and tree data, increment tree cores, and *Ribes* plant specimens were collected. The Yellowstone National Park plots

have a moderate level (12%) of white pine blister rust disease on whitebark pines, the host tree of the disease.

Title: **Trends in Climate and the Spread of White Pine Blister Rust in the Greater Yellowstone Ecosystem**

Principal Investigator: Ms. Laurie Koteen
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Objectives: In the summer of 1998, I obtained GIS coverages for a study relating infection levels of white pine blister rust to known forest habitat and cover types, and additional environmental variables. Preliminary to the GIS study, I have conducted a study of the region's climate from weather data obtained through the US Natural Resource Conservation Service. The aim of the study is to determine the current climatic conditions, which exist in the GYE with specific reference to the White Pine blister rust fungus, and its spread to the subalpine tree, whitebark pine. Secondly, through relating known infection and mortality levels of whitebark pine from blister rust through a GIS study, I aim to link environmental variables to the spread of this disease. Lastly, I am looking at scenarios of future blister rust change under climate change conditions.

Findings: Currently, I am in the finalizing stages of the review of climate data, and the assessment of climate change scenarios for the GYE. These findings will be published as a book chapter put out by the National Wildlife Federation. I have found that climate, although not most favorable to the spread of blister rust in the GYE, is not limiting, and that it is likely blister rust will increasingly be a source of mortality to whitebark pine in the GYE. Under projected climate change conditions, blister rust is likely to be even more of a problem region-wide. I am still in the preliminary stages of my GIS analysis.

Title: **Development of a Prototype Ecological Monitoring Program**

Principal Investigator: Terry McLendon
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Additional Investigators: W. Michael Childress

Objectives: 1.) Evaluate one to two revegetation/restoration projects at Yellowstone NP. 2.) Apply the EDYS ecological model to the revegetation/restoration projects and associated reference areas.

Findings: A vegetation monitoring design was established at two revegetation/restoration projects in July 1997. One was in a lodgepole pine community and the second was in a big sagebrush community.

Plots are to be established in both communities in 1999. Species composition and above and below ground biomass data are to be collected from these plots in the summers of 1999-2001. The 1999 data will be used to parameterize the EDYS ecological model for the sites. The model will be used to simulate successional dynamics and these results will be used to evaluate revegetation projects in these communities. The data collected in 2000-01 will be used to validate and improve the model. Initial simulation results are expected by summer of 2000. These will be supplied to Yellowstone National Park on an annual basis beginning in 2000.

Title: **AVHRR-NDVI as a Predictor of Temporal Change in Montana Grasslands**

Principal Investigator: Dr. Cliff Montagne
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Additional Investigators: Dr. Jerry Nielsen, David Thoma

Objectives: Determine degree to which AVHRR-NDVI satellite imagery can be used to predict vegetative above-ground biomass, or vegetative nitrogen content in grasslands.

Findings: The first field season of this project is complete. AVHRR-NDVI predicted live biomass well

($r^2 = 0.637$) for six grasslands when live biomass was below 1800 kg/ha. The strongest correlation with live biomass for an individual study area was $r^2 = 0.715$. Above 1800 kg/ha, a saturation asymptote was exceeded where predictive capability declined. AVHRR-NDVI did not predict dead biomass ($r^2 = 0.206$) at any level, or predict vegetative nitrogen content ($r^2 = 0.034$).

Title: **Wetland Conservation Planning**

Principal Investigator: Mr. Robert Moseley
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Objectives: Compile a centralized Wetland Information System for Idaho and prepare wetland conservation plans by watersheds. The first watershed to be done under this project is the Henrys Fork Basin.
Findings: Inventories were conducted in the Henry's Fork Basin but not in Yellowstone National Park this year.

Title: **Remote Sensing of Aspen Change on the Northern Range**

Principal Investigator: Dr. William J. Ripple
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Additional Investigators: Eric J. Larsen

Objectives: 1.) Using aerial photography, map changes in woody vegetation on Yellowstone National Park's (YNP) northern range and on selected comparable plots in the Shoshone National Forest (Clarks Fork of the Yellowstone river area) and Gallatin National Forest (Gardiner Ranger District). 2.) Compare changes in aspen/conifer canopy coverage on the northern range plots with changes observed on the Shoshone and Gallatin National Forest plots. 3.) Integrate field collected transect and core data with remote sensing results to attempt to determine the causes for any observed differences among the

study plots.

Findings: One hundred aspen plots were randomly chosen on the northern range of YNP along with 40 each in the Clarks Fork and Sunlight Basin study areas. Using aerial photography, aspen/conifer cover change for the period 1954 to 1992 (YNP) and 1958 to 1995 (Clarks Fork/Sunlight) is in progress.

During the 1997 field season, transect data was collected on 91 of the study plots, including 50 in YNP, 13 on the Clarks Fork, and 28 in the Sunlight Basin. Preliminary results indicate that YNP aspen stands have a different age structure than those in the Clarks Fork or Sunlight Basin areas. The data are being analyzed to compare ramet densities, the degree of conifer invasion, bark damage to boles, and intensity of grazing pressure on ramets.

At the conclusion of the 1998 field season, data had been obtained from 94 randomly selected plots in YNP, 97 plots in the Shoshone National Forest, and 67 plots in the Gallatin National Forest. Preliminary analysis of the data indicates that YNP aspen stands may have a different age structure than those in the adjoining national forests, including the elk wintering areas of the Sunlight/Crandall basins of the Shoshone National Forest. The data are being analyzed to compare age distributions, sucker densities, bark damage to boles, browsing intensity, and the degree of conifer invasion in aspen stands. Using paired sets of aerial photographs, aspen/conifer cover change for the period 1954-1992 (1958-1995 in the national forests) is still in progress with no findings to report as of yet.

Title:	**Effects of Water Stress and Elk Herbivory on Willows**
Principal Investigator:	Dr. Francis Singer
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Address:	Natural Resources Ecology Lab Colorado State University Ft. Collins, CO 80523
Additional Investigators:	Rex G. Cates, Linda C. Zeigenfuss

Objectives: Isolate the effects of drought stress versus intense herbivory on aboveground biomass production, nutrient status, and defense chemistry of willows through experimental manipulation.

Findings: Initial results show that willows subjected to no herbivory or 50% removal of annual production had greater height and catkin production than those subjected to 100% removal of production after four years of manipulation (1992-1995). Levels of carbon, nitrogen, and protein were lower, and cellulose was higher in *Salix pseudomonticola* plants that were subject to 100% removal compared to unmanipulated plants. Levels of several minerals were greater in 0% herbivory plants after four years of treatment; however, results after three years showed treated plants with higher mineral levels than 0% treatments. This implies that there may be short-term increases in minerals due to browsing or other factors, such as precipitation and temperature. Analysis of defensive chemistry has

found no significant differences in soluble carbohydrate content, phenolics, or tannins. This is contrary to responses found for similar work in Rocky Mountain National Park where conditions are more favorable for growth. Laboratory and data analysis has been completed at this point, and manuscripts for submission to refereed journals and reports to Yellowstone National Park are being written.

Title: **Physiology of Thermotolerant Plants in Yellowstone Park**

Principal Investigator: Dr. Richard Stout
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Objectives: Our three main objectives are to monitor rhizosphere and surface temperatures of vascular plants and mosses living in geothermally heated environments, to collect plant material from some of these plants for protein and nucleic acid analyses, and to collect seeds from some of these plants for physiological studies in the lab.

Findings: In 1998, we found that rhizosphere temperatures of plants living in geothermal soils ranged from 25 to 50 degrees C not only in the summer, but also during the winter months. We also found that heat shock protein expression was elevated in plant tissues exposed to temperatures above 35 degrees C, but not in tissues at temperatures below 35 degrees C. We also collected seeds from selected individuals of the following species: *Dichanthelium lanuginosum* and *Panicum capillare*.

Title: **Mechanisms of Grazing Impacts on Plant Competition**

Principal Investigator: Dr. Linda Wallace
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Objectives: Determine how plant species that have been found to compensate for herbivory compete with one another following tissue loss, so that we can examine how the plant community structures itself in these grazed ecosystems.

Findings: Analysis of plant biomass, nitrogen content, and soil nitrogen content was completed this year. These data corroborate the initial indications from last year's analysis of plant morphology and physiology. The three species in the artificial communities, *Bromus carinatus, Agropyron caninum*, and *Phleum pratense* appear to have a very simplistic competitive network. When *Phleum* was present, both of the other species did poorly. When *Phleum* was present only as the target plant, then the other species did better. *Bromus* was least affected, and *Agropyron* was dramatically reduced by the presence of *Phleum*. When *Phleum* was clipped, the nitrogen content of the other species was reduced, regardless of their clipping status. Thus, clipped *Phleum* was removing soil N at rates greater than could be matched by the other species. Soil N contents were quite high (averaging ~ 3000 ppm) and thus did not appear to be limiting to growth in this environment. The fact that *Phleum* was able to reduce the nitrogen content of the other two species in this situation is remarkable. Further analyses and object based modeling will be completed this year, as will submission of at least two manuscripts for publication.

Title: **Sagebrush Ecology and Mule Deer Relationships on the Northern Range**

Principal Investigator: Dr. Carl Wambolt

See Ecology

Title: **Declining Native Plant Diversity Caused by Invasive Weeds and Grazing**

Principal Investigator: Dr. Thomas Stohlgren
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Additional Investigators: Lisa Schell, Brian Van den Heuvel

Objectives: 1.) Identify major ecosystem level stressors and determine the diversity of rangeland grass species. 2.) Evaluate habitat and wildlife management practices, including grazing. 3.) Document the effects of noxious weeds/exotic plants on native flora. 4.) Develop standard survey techniques and protocols for vegetation sampling.

Findings: We found no significant differences in plant species richness (native and exotic) inside compared to outside of the three grazing exclosures (Lamar, Blacktail, and Junction Butte). The cover

of native species was usually higher inside the Yellowstone exclosures than outside. The exception was the sampling plot immediately outside Blacktail exclosure. The cover of native grass, *Agropyron spicatum*, varied greatly at the three exclosure sites, having inconsistent patterns in grazed or ungrazed plots. Overall, our sampling techniques of foliar cover found no consistent differences in the cover of forbs, grasses, or bare ground inside and outside exclosures. However, shrub cover in the grazed plots was consistently less than in the ungrazed plots. The cover of *Festuca idahoensis* was higher in grazed plots relative to ungrazed exclosure plots. Our addition of a third, 1000 meter sampling plot, randomly located in the grazed vegetation type, confirmed the natural patchiness of vegetation, spatially heterogeneous grazing, selective grazing, and inconsistent responses to grazing.

Title: **Mechanisms of Grazing Impacts on Plant Competition**

Principal Investigator: Dr. Linda Wallace

See Ecology

Title: **Survey and Assessment of Yellowstone Sand Verbena**

Principal Investigator: Ms. Jennifer Whipple
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Objectives: Yellowstone sand verbena (*Abronia ammophila*) is an endemic that is currently only known from a two-mile stretch of beach along the shoreline of Yellowstone Lake. There are extensive areas of similar shoreline habitat which have not been surveyed for Yellowstone sand verbena. During the summer of 1998, all of the unsurveyed possible habitat will be searched for this species. Also, permanent monitoring plots will be established.

Findings: Complete surveys of Yellowstone Lake, Delusion Lake, and Lewis Lake were completed during the 1998 field season. Three new sites of Yellowstone sand verbena were located. All known sites were counted in 1998 using a one meter squared grid system so that trends in any part of the population could be monitored through time. In addition, four permanent belt transects were established. A total of 8,325 sand verbenas were found among all of the sites. Determination of whether large sand verbena mats were composed of one or more individuals was difficult, so this number is a minimum count for the total population. Approximately 45% of the plants present last summer represent probable recruitment of the last two years. Less than 5% of the plants were at the three new sites,

thus the primary conservation concern needs to be still focused on the main population.

Title: **Yellowstone Flora**

Objective: The vascular plant flora of Yellowstone, even though investigated for approximately 120 years, is not completely known. The primary focus of this project is to improve the current knowledge of the flora of the park through in-depth collecting, especially of areas in the park which have not been previously studied. This includes inventory of the occurrence and range of native taxa and also involves the documentation of the arrival and spread of exotic species. In addition, collection of specimens for the Yellowstone herbarium will improve the value of the facility for both NPS personnel and outside researchers.

Findings: Ongoing inventory of vascular plants and collection for the Yellowstone National Park Herbarium. Four species of vascular plants previously not reported as occurring within the park were discovered. *Schoenocrambe linifolia* (Nutt.) Greene, plains mustard, and *Astragalus lotiflorus* Hook., lotus milkvetch, were both discovered in the northern part of the park. These native species are presumed to have been a long-term component of Yellowstone's flora that had been previously overlooked. Additionally, *Solidago rigida* L. var. *humilis* Porter, stiff goldenrod, was located on the Dunraven road during surveys for species of special concern. Stiff goldenrod is presumed to be a casual introduction since there was only one plant present on the immediate roadside. *Ranunculus acris* L., meadow buttercup, is an exotic species that has become established in the vicinity of the Bechler Ranger Station.

Title: **Postglacial Fire Frequency and its Relation to Long-Term Vegetational and Climatic Changes in Yellowstone Park**

Principal Investigator: Dr. Cathy Whitlock

See Fire

DATABASE

Title: **Scientific Research in Yellowstone National Park 1872-1997: a Bibliographic Guide and Database**

Principal Investigator: Ms. Cynthia Kaag
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Objectives: Compile a searchable Procite-based file of published and unpublished scientific research carried out in Yellowstone National Park since its inception.

Findings: Approximately 9000 records are currently in the database. Indexing and annotating is underway. The database is available on the Internet at: www.wsulibs.wsu.edu/ris/risweb.isa

Title: **Integrated Biogeochemical Database**

Principal Investigator: Dr. Daphne Stoner

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Objective: Develop an Internet accessible database and map server for cataloging and mapping microbial biodiversity. A prototype site has been launched on the Internet at: http://remus.inel.gov/ynp1

ECOLOGY

Title: **Defensive Chemistry in Willows in Yellowstone's Northern Winter Range: An Indicator of Plant Health, Habitat Quality, and Susceptibility of Elk**

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Additional Investigators: Jiping Zou, Lauryl Mack, Francis J. Singer, Linda Zeigenfuss

Objectives: Over the last 60 years, large decreases in willow (*Salix*) populations and status have occurred in the northern winter range in Yellowstone National Park, Wyoming. These declines have been extensive and dramatic since the mid-1930s. Reasons for these declines are varied but generally include elk population effects, climate variables, and beaver dynamics. Our central hypothesis is that changes in water dynamics due to reduced precipitation, higher temperatures, reduced flooding, lowered water tables, and the absence of beaver are the causal factors driving the willow declines. Changes in these factors result in willow physiology that is unable to produce natural defenses against ungulates. As a result, willows growing in these unfavorable habitats become nutritionally more suitable to elk, and are not able to grow beyond their reach. The specific hypothesis tested and reported on in this paper is that willows inside exclosures, from which the current growth was mechanically clipped at 50% and 100% levels, will not be able to respond by increasing potentially defensive phenolic and tannin compounds. The response in carbohydrates is ambiguous, but is expected to be a decrease in the presence of mechanical clipping compared to the control.

Findings: For *S. bebbiana* willows clipped inside three exclosures at 50% and 100% of the current annual growth over four years, phenolic concentrations as determined by high pressure liquid chromatography did not increase significantly when compared to the control. The overall pattern from samples collected during winter or summer was no change for the 50% treatment, and occasional decreases in phenolics in the 50% and 100% treatments. Tannins as analyzed by the butanol-HCL method showed no significant increases, most often remained unchanged, or carbohydrates as analyzed by gas chromatography showed no changes in the treatments as compared to the control except one case where they significantly decreased. For *S. pseudomonticola*, phenolics did not increase in either treatment compared to the control,

and tannins did not change significantly in the 100% clip. Carbohydrates either did not change or decrease significantly in either 50% or 100% treatments for both summer or winter compared to the control. This data is strongly supportive of the premise that willow decline is due to unfavorable growing conditions on the northern winter range and that willow physiology is negatively impacted. Voucher specimens are in the herbarium at Brigham Young University.

Title: **Ecology and Distribution of Red Fox (*Vulpes vulpes*) in Northern Yellowstone**

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Additional Investigators: Robert Fuhrmann, Brad Swanson

Objectives: 1.) Determine habitat use of northern Yellowstone's red fox. 2.) Examine the genetic variability of red fox subpopulations according to three elevational zones.

Findings: Bob Fuhrmann completed his M.S. degree under the direction of Bob Crabtree and Lynn Irby (co-advisors). Results show that red fox prefer forested and forest-edge habitats. Populations above 7,200 feet in elevation are genetically isolated from below 7,200 feet populations and constitute a new subspecies of mountain red fox, indigenous to North America. We continued monitoring of a radio-tagged red fox in the Lamar Valley area, and visually documented many red fox sightings and interactions with other carnivores.

Title: **Medium-sized carnivore project**

Additional Investigators: M. Miller

Objectives: 1.) Assess several methods to inventory and monitor medium-sized carnivores: weasels, otter, wolverine, marten, fisher, lynx, bobcat, mountain lion, fox, coyote, and gray wolf. 2.) Examine various habitat and landscape characteristics related to their presence/absence. 3.) Conduct presence/absence surveys in Yellowstone National Park and surrounding wilderness areas.

Findings: Prepared manuscript on the evaluation of three detection methods for medium-sized carnivores. Conducted additional surveys for these rare carnivores in surrounding lands just outside Yellowstone National Park and prepared publications for submission to scientific journals. This project resulted in the confirmation of fisher in the Yellowstone Ecosystem.

Title: **Specificity of Ectomycorrhizal Symbioses**

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Additional Investigators: Sharon Cullings, J.R. Blair, Debie Kinsey, Robert Douglas

Objectives: Overall to test conflicting hypotheses regarding specificity in ectomycorrhizal interactions. The traditional view is that most plants will associate with many fungi, and the conflicting hypothesis is that some level of specificity is the rule rather than the exception in forest ecosystems. Specifically, 1.) To determine whether specificity exists in the ectomycorrhizal community; 2.) To determine effects of disturbance and chemical gradients on ectomycorrhizal community structure and specificity patterns.

Findings: 1.) Specificity exists in old-growth stands: manuscript submitted. 2.) Competition among mycorrhizae of different tree species is important in succession: manuscript submitted. 3.) Soil chemistry changes associated with lower pH of thermally altered soils affect mycorrhizal community structure: manipulation to litter layer and photosynthetic capability of spruce, pine and fir have been done. Analysis of below ground effects will begin summer 1999.

Title: **Productivity Gradients in Benthic Stream Invertebrate Diversity of the Intermountain West**

Principal Investigator: Dr. Russell Death
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Additional Investigators: Fiona Death, Chuck Hawkins, Mark Vinson

Objectives: To investigate the effect of productivity on stream invertebrate diversity.

Findings: 63 Streams from Great Basin National Park, Nevada, in the south through to Yellowstone National Park, in the north, were sampled in June (spring) and/or October (fall) 1998 following the

protocol outlined for project one. Streams of Yellowstone National Park, Shoshone National Forest, G9, D2, D3, and D4 were only sampled in October 1998; all others were sampled at least twice, once in June and again in October

Title:	**Assessing Ecosystem Integrity: An Approach Modeling Energy Flow**

Principal Investigator:	Dr. Walter Duffy
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Additional Investigators:	Diane E. Ashton

Objectives: 1.) To compare wetland aquatic invertebrate production estimates and P/B ratios from stressed and non-stressed ecosystems. 2.) To evaluate the use of energy flow/flux in monitoring ecosystem integrity.

Findings: We have identified 187 taxa in samples from Yellowstone National Park wetlands. Of these, 131 (70%) had not previously been reported from the park. Community structure of aquatic invertebrates in wetlands was influenced by duration of flooding and presence of salamander larvae. A book chapter detailing these findings will be published in spring 1999.

Collections are housed at the California Coop. Fish. Research Unit, Humboldt State University, Arcata, CA 95521

Title:	**Snow Pack on Northern Range**

Principal Investigator:	Mr. Phillip Farnes
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Objectives: Determine snow pack distribution across the Northern Range and compare measured snow water equivalent to estimated snow water equivalent and develop a procedure for estimating sinking depths in the snow. Compare snow variation with plant and animal responses.

Findings: Plants, animals, and fish respond to weather conditions more than they do to time periods, and responses are predictable for different weather conditions.

Title: **The Sustainability of Grazing Ecosystems**

Principal Investigator: Dr. Douglas Frank

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Additional Investigators: Dr. Peter Groffman

Objectives: The objective of this study is to examine the effects of ungulates on carbon and nitrogen flows in grasslands and shrub-grasslands in Yellowstone National Park.

Findings: The 1998 field season was primarily devoted to locating and setting up study sites. We established ten sites on winter, transitional, and summer ranges, located at Stevens Creek, Mammoth, Blacktail Plateau, Specimen Ridge, Crystal Bench, Soda Butte, Gardiner's Hole, Norris, Canyon, and the Hayden Valley. At each site we erected a 12 x 12 m exclosure, and installed 12 minirhizotron tubes (clear, plastic, 2.5 cm diam) to measure shoot and root growth in grazed and fenced, ungrazed grassland. No sites are visible from the road.

Title: **A New Application for Natural ^{15}N Abundance to Examine the Effect of Large Herbivores on N Cycling**

Objectives: 1.) Determine the effect of large herbivores on N cycling in the northern winter range of Yellowstone National Park, particularly their influence on rates of net N mineralization, denitrification, and ammonia volatilization. 2.) Determine how grazers alter natural abundance of ^{15}N of grassland soil and plants, and the mechanisms responsible for the isotopic shift.

Findings: We've used a combination of stable isotopes and more conventional soil incubation methods to demonstrate that grazers accelerate net N mineralization in Yellowstone's northern winter range. Grazers doubled the rate of N availability to plants, while simultaneously increasing the spatial variation of that rate. The facilitation of N cycling by grazers is, no doubt, a component of the positive feedback that grazers have on their forage production, which Sam McNaughton and I determined previously (Frank and McNaughton 1993). We also measured rates of denitrification in the northern winter range. We found that denitrification was low (<1 kgN/ha/yr) at dry sites, which dominate the winter range, and ungulates had no effect on the rate. However, at mesic sites, denitrification was higher (> 1 kgN/

ha/yr) and was stimulated by ungulates.

Title: **Landscape Heterogeneity and Bird Diversity under Natural and Human Disturbances in the Greater Yellowstone Ecosystem**

Principal Investigator: Andrew Hansen
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Additional Investigators: Jay Rotella

Objectives: 1.) Quantify landscape pattern under natural disturbance (wildfire) and human activities (logging). 2.) Compare landscape patterns in Greater Yellowstone with those in the Pacific Northwest. 3.) Examine the relative influences of stand and landscape pattern and primary productivity on bird diversity and demography. 4.) Quantify the distribution of abundance of birds, trees, and shrubs in the GYE and potential controlling factors. 5.) Examine the population viability of the subset of bird species considered most at risk.

Findings: 1.) Abiotic factors including climate, topography, and soils cause species richness to be high only in localized hotspots that are mostly at lower elevations on private lands. 2.) Intense human land use is concentrated on these hot spot areas. 3.) These biodiversity hot spots are population source areas for some bird species, except where intense human land use has favored nest predators and brood parasites, and caused the hot spots be become population sinks.

Status: We are in the third year of this six-year study.

Title: **The Ecology of the Mountain Lion in Yellowstone National Park**

Principal Investigator: Dr. Maurice Hornocker

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Additional Investigators: Dr. Kerry M. Murphy

Objectives: 1.) Document population dynamics and characteristics. 2.) Document social organization. 3.) Document predator-prey relationships

Findings: Cougar predation, interactions with bears, and reproductive success (RS) were studied from 1987 to 1996 in northern Yellowstone National Park and vicinity. Eighty-seven cougars were captured, radiocollared, and monitored. Reproductive success was estimated using field observations and by documenting allelic inheritance at microsatellite loci. Elk (*Cervus elaphus*) and mule deer (*Odocoileus hemionus*) comprised 98% of prey biomass and 81% of 302 cougar kills. Bighorn sheep (*Ovis canadensis*), moose (*Alces alces*), and pronghorn (*Antilocapra americana*) represented less than 5% of cougar kills. Elk calves were the most important prey, mule deer intermediate, and cow and bull elk the least important prey relative to their availability. Predation rates averaged 9.4 days per ungulate kill and varied by cougar hunting experience (measured by age), weight, and ambient air temperature. Cougars killed only 2-3% of elk and 3-5% of deer on the study area each year. Migratory behavior, habitat use patterns, and the size of prey reduced the effects of cougar predation. Cougars did not effectively limit growth rates or elk and moose because cougars selected their young preferentially to adults. Strong limitation of mule deer was more likely, because all sex-age classes were preyed upon more equitably. Our results supported Ackerman et al.'s (1986) conclusion that altering the structure of cougar populations (e.g., by hunting) could change the influence of cougars on the numbers and sex-age structure of their prey.

Black bears (*Ursus americanus*) or grizzly bears (*Ursus arctos*) visited 19 of 58 cougar kills from 1990 to 1995. Cougar predation provided an average of 1.9 kg per day of biomass to bears, or up to 113% of bears' daily energy needs. Cougars that were displaced from their kills lost an average of 0.64 kg per day of ungulate biomass, or 17 to 26% of their daily energy requirements, losses which could be significant to cougars.

Cougar RS varied among individuals of both sexes, particularly males. Reproductively successful males were typically residents that exceeded 30 months of age. Resident males only sired litters within their territories. Nonresident males sired few litters, if any. The number of breeding-age females inside a

male's territory was related to his RS, but his territory size was a poor predictor.

Title: **Bison Forage Relationships in the Madison-Firehole Area of Yellowstone National Park**

Title: **Determining Forage Availability and Forage Use Patterns in the Hayden Valley**

Title: **Impacts of Roads on Movements and Habitat use of Bighorn Sheep on the Northern Range**

Principal Investigator: Dr. Lynn Irby

See Wildlife Management

Title: **Coarse Woody Debris and Site Productivity in Rocky Mountain Coniferous Forests**

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Additional Investigators: Daniel B. Tinker, Dr. George Vance

Objectives: To quantify the dynamics of coarse woody debris following fire regimes of varying intensities, and to develop a model to simulate natural ecosystem processes which might affect the coarse woody debris dynamics. Similar data from various harvesting practices in southeastern Wyoming will be compared to the data from a natural, undisturbed system, to see if coarse woody debris biomass is within the range of natural variability as predicted by the Yellowstone model.

Findings: The first several months of 1997 were spent entering and analyzing data collected during the 1996 field season. This work included the construction of digital maps in GIS for use in our simulation model, which is currently under development. We hope to model the dynamics of coarse woody debris over centuries following natural disturbances such as fire and human-caused disturbances such as clearcutting. The 1997 field season began with additional data collection from clearcut and uncut stands in the Medicine Bow National Forest in southeastern Wyoming. These data, including forest floor biomass and spatial maps of coarse woody debris, will be compared to comparable data from

Yellowstone in burned and unburned stands. In late-June, the fieldwork resumed in Yellowstone National Park, where six new sites were added during the summer to the 12 sites previously established. In addition to the coarse woody debris biomass data and construction of spatial maps at each site, new data were collected to begin to estimate the amount of wood that is consumed or converted to charcoal during fires. For this work, we established a new field site near Pelican Creek, the site of a relatively large, intense crown fire that occurred in August of 1996. The investigation of this site was very valuable, as it provided evidence regarding the combustion of wood which apparently persists only for a year or two, and that has largely disappeared from sites burned in 1988. At the Pelican Creek site, we tested new methods of estimating the amount of wood that burns during fires, and are presently analyzing and interpreting those data.

With regard to the effects of coarse woody debris on soil organic matter formation, we collected forest floor and soil samples from several burned sites. Among these sites was the site of the Arrow fire in northern Yellowstone that burned in 1976 and again in 1988. We will compare chemical characteristics of the soil samples to those in unburned sites in Yellowstone, and to clearcut and uncut sites in the Medicine Bow National Forest to try to understand the effects of various disturbances on soil organic matter quantity and quality.

We are continuing to analyze biomass data and construct digital maps, and are evaluating the quality and amount of the data to aid in the planning of the upcoming 1998 field season.

We spent the first several months of 1998 entering and analyzing new data collected during the 1997 field season. In addition to the coarse woody debris biomass data and construction of spatial maps at each site, new data were analyzed, estimating the amount of wood that is consumed or converted to charcoal during fires. A new field site near Pelican Creek was established in 1997 where a relatively large, intense crown fire occurred in August, 1996. The investigation of the Pelican Creek site was very valuable, as it provided evidence regarding the combustion of wood which apparently persists only for a year or two, and that has disappeared from sites burned in 1988. Using this evidence, we have developed new methods of estimating the amount of wood that burns during intense natural fire that we feel have provided a reasonable first estimate of wood combustion. We found that approximately 8 percent of downed wood was completely consumed and an additional 8 percent was converted to charcoal. Later in 1998, we also began initial simulations and validation exercises for the simulation model to predict the spatial variability of coarse woody debris through time. These results will be forthcoming during 1999.

Title: **Study of the Effects of the 1988 Wildfires on Yellowstone Stream Ecosystems**

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Additional investigators: A. Marcus

Objectives: The overall objective of this study is to separate the early from the delayed effects of wildfire on stream ecosystems in Yellowstone National Park. Specific goals include documenting changes in stream habitat and biota each successive year following the 1988 wildfires, thus providing a basis for predicting and evaluating subsequent long-term changes. Few streams greater in than size than 4th order were substantially affected by the fires and this study focuses on streams of 1st through 4th order. To increase the breadth and precision of the study and to provide more general conclusions, each size class (order) is represented by four to five streams, as well as by at least one reference stream that was not affected by the fires.

Since 1993, the research has been limited to streams in the Cache Creek drainage basin, due to financial constraints. This has meant elimination from the study design of reference sites (except for Amphitheater in 1997), and much of the sampling replication. Nevertheless, samples from one of the most intensively burned watersheds (Cache) are being collected each year (other than 1996) through cooperation with Yellowstone Ecosystem Studies (YES). However, in 1998 sampling of all the original sites was completed.

Findings: Although the effects of fire were evident in early years of this study, the streams could be characterized as being largely on a "fast recovery track" (Minshall and Brock 1991). However 1991 and 1994 were marked by runoff events which caused substantial alteration of physical habitat in the streams in burned watersheds, particularly those in moderate to steep gradients. Even greater physical alterations occurred in 1995 (and probably in 1996), and were evident again in 1997. The dramatic changes in 1995-1997 are associated with a general increase in precipitation in those years. Disturbances such as these are reflected in declines in the biotic components of the stream and serve as important "resets" in the recovery process (Minshall et al. 1989, Minshall and Brock 1991). However, as was evident from examination of one of our reference streams (Amphitheater) this year, some of those differences are more a response to a change in annual weather conditions than to fire per se. Results from our 1998 studies suggest that the significant changes in channel geomorphology and stream ecology seen in 1997 may have stabilized, at least for the time being. For stream sizes examined, conditions are still far from pre-fire conditions and the return trajectory is longer, more varied, and less certain than previously thought.

Title: **Statistical Methods for Assessing Complex Ecosystem Processes and Population Dynamics – A Case Study of Yellowstone and Teton National Parks' Shiras Moose**

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Objectives: Houston (1968) described a complex process involving both environmental and population level variables that he believed were the ultimate determinants of moose population size. The objective of this study is to develop statistical methodologies that will allow researchers to devise and test hypotheses regarding the function of complex ecological systems and how these systems impact populations such as the Shiras Moose. Results should allow researchers to quantify the effects of system parameters. In addition, results should allow researchers to perform statistical hypothesis tests that allow for overall model acceptance or rejection.

Findings: Models have been developed using Structural Equation Modeling methods which perform well and meet the objectives stated above. A manuscript is currently in preparation for publication.

Title: **Effects of Depleted Amphibian Populations on the Community Ecology of Alpine Ponds**

Principal Investigator: Dr. Wendy Roberts
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Objectives: I wanted to test the impact of anuran tadpoles on the food webs of alpine ponds.

Findings: This project involved two parts, experimental manipulations in enclosures and landscape-level comparison of unmanipulated ponds with and without tadpoles. In separate experiments, I stocked three blocks of enclosures with or without tadpoles of *Rana luteiventris* and *Bufo boreas*. In the experiment with *Bufo boreas* tadpoles, I compared their impacts with those of freshwater snails. Every

two weeks until tadpole metamorphosis, I measured tadpole and snail length, and collected samples of algal biomass. Results showed the *Rana luteiventris* tadpoles depressed algal biomass after two weeks of growth, but not after four weeks. *Bufo boreas* tadpoles did not depress algal biomass, but snails did. In the landscape-level, project I compared eleven unmanipulated ponds, five with tadpoles and six without. This comparison did not show a statistically significant impact of tadpoles on algal biomass. Results of the two phases of this project suggest that enclosures accurately mimicked conditions in whole ponds, and that tadpole grazing had a complex influence on algal biomass, rather than a direct negative impact.

Title: **Effects of Fire Size and Severity on Early Succession and Aspen Seedling Establishment**

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Additional Investigators: Monica G. Turner, Gerald A. Tuskan, Dennis H. Knight

Objectives: 1.) Sample density and survival of aspen seedlings throughout the areas burned in 1988. 2.) Determine experimentally the effects of ungulate browsing, plant to plant competition, micro-climate, and genetics on survival and growth of aspen seedlings. 3.) Measure plant cover, density, and diversity in permanent plots established in 1990 throughout the areas burned in 1988. 4.) Predict and map the early successional pathways of areas burned in 1988 on the basis of percent serotinous lodgepole pine trees, size of burned patch, and local severity of fire. 5.) Map percentage of serotinous trees across the landscape. 6.) Measure aboveground net primary productivity and leaf area index in stands representing different initial pathways of plant succession following the Yellowstone fires of 1988.

Findings: 1.) Aspen seedlings are most abundant in burned forests of the western and west-central portions of Yellowstone NP, along the Madison and Firehole Rivers. 2.) Experiments on the effects of browsing and competition are ongoing. So far, the plants have shown relatively little response to protection from browsing or to removal of local competitors. 3.) Trends in plant cover, density, and diversity that were measured from 1990-1993 generally continued through 1996. The permanent plots will be re-sampled in 2000. 4.) We obtained high-resolution aerial photos of the entire park area in August 1998, and are using these photos to map areas that burned in 1988 and now exhibit high-density lodgepole pine, low-density lodgepole pine, or non-forest vegetation. 5.) Initial sampling of percent serotiny indicated highest percentages in the west-central portion of Yellowstone NP. 6.) Productivity and LAI will be sampled in 1999.

Title: **Effects of Water Stress and Elk Herbivory on Willows**

Principal Investigator: Dr. Francis Singer

See Botany

Title: **Forest Health Monitoring**

Principal Investigator: Dr. Dwane Van Hooser
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Objectives: Monitor long term health of forests in Wyoming (and surrounding states).

Findings: No reports have been released yet.

Title: **Mechanisms of Grazing Impacts on Plant Competition**

Principal Investigator: Dr. Linda Wallace
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Objectives: To determine how plant species which have been found to compensate for herbivory compete with one another following tissue loss. This will help us determine how the plant community structures itself in these grazed ecosystems.

Findings: *Phleum pratense* L. (Timothy) was introduced into Yellowstone National Park early in its history. Since then, this species has spread across the northern range as well as into many of the grasslands found on the subalpine plateau. Questions about this species include: how is it affecting ecosystem processes in the grasslands, how is it affecting community structure in grasslands, what may be the long-term ramification of this specie's presence in Yellowstone? Results from a massive experiment conducted on the northern range using *Phleum pratense*, *Agropyron caninum*, and *Bromus carinatus* indicate that *P. pratense* is competitively superior to these two native species. The mechanism of competition is via the roots. *P. pratense* is able to procure water and nutrients at the expense of the native species. This

superior procurement occurs whether or not the plants are grazed, i.e., grazing does not influence the direct competitive interactions among these species. Grazing does differentially influence flowering (sexual reproduction). *P. pratense* can flower regardless of grazing intensity, whereas grazing strongly inhibits flowering in the native species. A study analyzing the physiology and genetic make-up of two populations of *P. pratense* found that there is a high level of heterozygosity in *P. pratense*, which allows it to occupy a wide variety of habitats. Some of this specie's ability to flourish in different habitats appears to be genetically fixed because plants brought back to Oklahoma and grown in a common garden showed drought and grazing tolerance commensurate with their field habitat. There is not much the park can do about *P. pratense*. Over time, it appears that species and genetic diversity in the grasslands may be decreased, available soil water and nutrient levels may drop, and the higher-elevation grasslands of Yellowstone will continue to be altered.

Title: **Sagebrush Ecology and Mule Deer Relationships on the Northern Range**

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Additional Investigators: Reyer Rens

Objectives: 1.) To determine the current status of the sagebrush-shrub community on the northern Yellowstone mule deer winter range. 2.) Determine the importance of the sagebrush-shrub community to wintering mule deer and elk. 3.) Describe the effect of human-caused and natural fire, including interactions with browsing, on sagebrush ecology on the northern Yellowstone winter range. 4.) Determine what management techniques can be implemented to preserve or enhance mule deer and elk habitats associated with sagebrush-shrub communities.

Findings: Mule deer utilize the several sagebrush habitat types in the boundary line area as key wintering types. They use the four woody sagebrushes and three rabbit brushes heavily as browse, although they display a decided preference among taxa on winter range. None of the sagebrushes have reestablished very well following burning as long ago as 19 years. The rabbitbrush taxa have responded to burning somewhat better, but heavy browsing has not allowed them to attain a very significant role in their respective habitats. Some mountain big sagebrush plants establish most years, but some years are enormously more important for establishment of the taxon. Communities of older sagebrush plants are more productive than those of younger plants. Sagebrush production can be modeled using taxon and form class with great accuracy. Significant differences exist in the development of protected and

browsed shrubs of big sagebrush habitat types. Preliminary information indicates that wildfires and ungulate browsing interact as determinants of sagebrush recovery. The actual degree of interaction varies among sites that differ in environmental conditions.

Title: **Community Position and Pattern along a Continuous Thermal Gradient: Physical and Biological Constraints**

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Objectives: The objectives of the current phase of the project is to follow the long term dynamics of the organisms in thermal communities in the temperature range from 45 degrees C down to ambient.

Findings: During the past year, research activities at Yellowstone National Park included continued censuses of emerging adults of the dragonfly (*E. collocatus*) and whole system censuses of selected thermal communities located in West Thumb; Upper, Midway, and Lower Geyser basins; and areas along the road from Madison Junction to Mammoth Hot Springs. I also spent a small amount of time searching other, more isolated thermal areas for thermal communities unusual in terms of either temp/nutrients or animal/plant species. No additional sites were added last year. A paper on the comparative ecosystem work is in preparation. One objective is to compare long-term variability in the systems. A second objective is to explore the variability with the various classes of thermal community, i.e., hot (>40 degrees C.) or warm (<40 degrees C.), as well as the water chemistry - alkaline or acid.

The dragonfly census work is done in Gentian Stream, Serendipity Meadow, just off of Firehole Lake Drive in the lower Geyser Basin. I now have 20 years of total emergence counts and am trying to get temperature/precipitation data from the Old Faithful weather station to see if the large year-to-year variability in production of adults is related to weather. I have also begun to measure stream and local air temperatures with data loggers in place all year. Two papers on this work are started, but will require at least two to three more years of data.

ENTOMOLOGY

Title: **Effect of Clover-Mist Fire on Selected Biting Fly Populations and Cytogenetics of Western Black Fly Species**

Principal Investigator: Dr. John Burger
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Objectives: 1.) To sample selected large and small streams for selected taxa of black flies as part of a treatment of the fauna of North America. 2.) To process samples using cytogenetic techniques for analyzing polytene salivary chromosomes to resolve species complexes of western black flies. 3.) To examine the impact of the Clover-Mist fires on the populations of Tabanidae in the Lamar River Drainage and of Rhagionidae in the Miller Creek Drainage to determine the effect of fire on host-seeking behavior of these flies.

Findings: Work on this project was completed in 1996. No further collections have been made since then. A volume on the black flies of North America is scheduled to be published late in 1998 and will incorporate information from this project. This project is now completed.

Title: **Elevational Distribution of Mosquito Species**

Principal Investigator: Ms. Patricia M. Denke
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Additional Investigators: J. E. Lloyd, J. L. Littlefield

Objectives: To examine the distributions of mosquitoes of the genus *Aedes* (Diptera: Culicidae) with

regard to physical environmental variables (elevation, date, water temperature, pH) and biotic variables (habitat). To create a predictive system for determination of mosquito communities in pools based on the above information.

Findings: I have not taken specimens from the park for several years. Several of the species present in the area are confined to specific elevational intervals (i.e., below 1,500 m or 2,000 m) or to certain time periods within the year. The presence of some species is also strongly correlated with the habitat of the pools, such as shading by coniferous trees or open with grass. Although the temperature of the water and the pH do help determine which species may be present, these are not strong predictors unless they are taken in context with the other variables. There are two additional variables that can add weight to predictions of the mosquito community, which are larval density (some species are not found in samples with high densities), and which of the other species are present (there are at least 25 species of *Aedes* present in the park). When taken as a coherent whole, the presence or absence of about 15 species can be fairly accurately predicted. Specimens of each species will be deposited in the MSU-Bozeman entomology collections.

Title: **Butterflies of Yellowstone and Grand Teton Parks (also Odonata)**

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Additional Investigator: Ms. Mardell Oleta Moore

Objectives: To produce field guides about the insects of Yellowstone and Grand Teton National Parks. Photographs need to be taken of all species in the parks. Data & photos only need to be obtained. No specimens are collected. All specimens are safely netted, photographed, and released alive in the area of the park where they were discovered by the researchers.

Findings: In 1997, several activities were accomplished. We took slide photographs of the entire Dragonfly collection at the Albright Museum in Mammoth. An entire set of the 34 slides was sent and donated to Museum Curator Susan Kraft. Slide photographs of at least 15 different species of dragonflies were taken in the field during 1997. Twenty slides of butterflies were taken in the field during 1997. Work continues on preparing the text and photos for the field guide to butterflies.

In 1998, ten species of dragonflies were successfully photographed for field guides. Four species of damselflies were also photographed. A diptera (fly) was photographed pollinating the sand verbena. Copies of all prints were given to the park's botanist for the record. While the researchers and park

botanist believe this is not the only pollinator, it is the first time any pollinator has been seen and captured on film.

Title: **The Mosquitoes of Yellowstone National Park: A Study on Biology, Behavior and Distribution**

Principal Investigator: Dr. Lewis T. Nielsen
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Salt Lake City, UT 84117-5378

Objectives: A continuing study of the mosquitoes of Yellowstone National Park concerning species present, their distribution, biology, and behavior.

Findings: Final collections were made in May and June of 1994. It appears that mosquitoes which were reduced significantly in number and species in the study areas during the 1990 season made a steady comeback, and by the time of the 1994 collections, were back to pre-fire levels. It should be noted that populations of mosquitoes in the park normally fluctuate in response to temperature and amounts of yearly precipitation. Low levels of mosquitoes in the park have occurred in the past during very warm spring and early summer weather after lower than normal precipitation, i.e., larval habitats dry up before mosquitoes complete development to adults. It appears that fires do not have a long-term affect on mosquito numbers, but if the habitat is altered, such as by removal of shade, species competition may change.

A detailed report on Yellowstone mosquitoes was published in the *Journal of the American Mosquito Control Association*, 12(4): 695-700, 1996. Collections are held in the University of Utah Biology Department.

Title: **Gypsy Moth Survey**

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Additional Investigators: Carol Randall

Objectives: To detect the presence of alien gypsy moths in Yellowstone National Park.

Findings: In 1998, 73 monitoring traps were placed parkwide. An additional 16 delimitation traps were placed in the Mammoth area, since 2 moths were trapped in the Mammoth Campground in 1997. All traps were installed by June 20 and were removed by October 15. One trap, located in the Lake developed area, caught a gypsy moth. Delimitation in the Lake area will be conducted in 1999.

Title: **Community Position and Pattern along a Continuous Thermal Gradient: Physical and Biological Constraints**

Principal Investigator: Dr. Richard Wiegert

See Ecology

Title: **Respiratory Physiology and Habitat Selection in Thermophilic Aquatic Insects.**

Principal Investigator: Dr. Brent Ybarrondo
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Objectives: To understand respiratory physiology and habitat selection decisions in thermophilic aquatic insects, including water scavenger beetles (Coleoptera: Hydrophilidae), and both adult and nymphal stages of dragonflies and damselflies (Odonata).

Findings: Odonate niads from thermal pools were found to exhibit thermal preference in the laboratory. Hydrophilid respiratory complex (plastron + macroplastron, or bubble) functions primarily as an oxygen reservoir at water temperatures greater than ca. 5 degrees C. Future research will investigate: 1.) The degree to which the respiratory complex function as a physical gill at low water temperatures (ca. T_w = 0 to 5.0 C); 2.) The degree to which adult male dragonflies exhibit thermal preference in controlling oviposition territories in thermally variable environments (e.g., Firehole River study site); and 3.) Development rates of odonate niads as a function of water temperature and dissolved oxygen tension will be investigated.

Findings to date provide the basis for two NSF proposals to support continuing research. One was submitted in fall 1998, and the other will be submitted in fall 1999 following field work at Yellowstone during summer 1999.

EXOTICS

Title: **Assessing the Expansion Risk of an Exotic Snail across Habitats**

Principal Investigator: Dr. Mark Dybdahl
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Objectives: We will collect an exotic species of snail (*Potamopyrgus antipodarum*), estimate their density in different locations, measure genetic (clonal) diversity of invading populations, estimate their life-history characteristics, begin a preliminary assessment of their effect on native aquatic macroinvertebrates, and establish sites for future monitoring.

Findings: I determined the extent of the distribution of *Potamopyrgus antipodarum*, an exotic freshwater snail, in the major streams of the watershed of the Madison River during three collection trips from July to September 1997. I established sampling locations along these rivers and sampled snails for estimates of density, clonal diversity, and life-history characteristics. Densities were extremely high in the Firehole River from its mouth to the area of Old Faithful, but no exotics were found upstream. Densities were also very high in Nez Perce Creek and the Madison River. Low densities were found in a very patchy distribution in the Gibbon River. Preliminary genetic analyses suggest that the exotic population is dominated by one clone.

In 1998, I again determined the extent of the distribution of *Potamopyrgus antipodarum* in the major streams of the watershed of the Madison River during collection trips from March to September 1998. I re-sampled snails from established locations along the Madison, Gibbon, and Firehole Rivers. The goal was to determine the phenology and seasonal life history traits of snail populations. These collections will be analyzed for estimates of density, clonal diversity, and life-history characteristics. Snail densities and life history traits respond to physical characteristics of these rivers. Clonal diversity was very low. One additional specific goal was to map snail populations and life-history traits across invasion fronts. We collected snails along two invasion fronts, where snail populations grade from extremely dense, to sparse, to absent. Samples are currently housed at Ohio University and Montana State University.

Title: **Pest Trend Permanent Plots for White Pine Rust**

Principal Investigator: Ms. Jeri Lyn Harris

See Botany

Title: **Distribution of *Potamopyrgus antipodarum*, the New Zealand Mud Snail, in the Greater Yellowstone Ecosystem**

Principal Investigator: Dr. Billie Kerans
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Objectives: 1.) Document the distribution of *P. antipodarum* in drainages of the Madison River. 2.) Determine correlations among the relative abundance of *P. antipodarum*, other benthic macroinvertebrates, and abiotic characteristics of study reaches. 3.) Evaluate sites for future experimental work on the effects of *P. antipodarum* on benthic assemblages

Findings: *P. antipodarum* was found at all sampling locations in the Madison River and Nez Perce Creeks. Snail densities ranged from 47,000 to 300,000 individuals per m^2 in the Madison and 1,100 to 97,000 individuals per m^2 in Nez Perce Creek. In the Gibbon River, the mud snail was found at only two locations, both of which were immediately above Madison Junction. Snail density at these sites ranged from 22 to 24,000 individuals per m^2. In the Firehole River, snails were found upstream from Madison Junction to the upper limits of thermal influence. Densities in this section ranged from 11,000 to 102,000 individuals per m^2. The mud snail was not found upstream of the geyser basin. All other invertebrates found in the samples with *P. antipodarum* have been identified and counted. The data on physical features of the habitats and other benthic invertebrates is currently being correlated with *P. antipodarum* densities. These correlations will suggest the conditions under which mud snail densities are high and also whether or not the mud snail influences the other invertebrates. Data analyses are still in progress. The above analyses were based on samples in cobble habitat. Samples have also been taken in habitats with vegetation and in soft sediments. Voucher specimens of the mud snail will be deposited in the Invertebrate Museum on the campus of Montana State University.

Title: **Trends in Climate and the Spread of White Pine Blister Rust in the Greater Yellowstone Ecosystem**

Principal Investigator: Ms. Laurie Koteen

See Botany

Title: **Declining Native Plant Diversity Caused by Invasive Weeds and Grazing**

Principal Investigator: Dr. Thomas Stohlgren
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Additional Investigators: Lisa Schell, Brian Van den Heuvel

Objectives: 1.) Identify major ecosystem level stressors and determine diversity of rangeland grass species. 2.) Evaluate habitat and wildlife management practices, including grazing. 3.) Document the effects of noxious weeds/exotic plants on native flora. 4.) Develop standardized survey techniques and protocols for vegetation sampling.

Findings: We found no significant differences in richness of native or exotic plant species between the inside and outside of three grazing exclosures (Lamar, Blacktail, and Junction Butte). Except for the sampling plot immediately outside the Blacktail exclosure, the cover of native species was higher inside the exclosures. The cover of native grass, *Agropyron spicatum*, varied greatly among the exclosure sites, having inconsistent patterns in grazed and ungrazed plots. Overall, our sampling techniques found no consistent differences in the cover of forbs, grasses, or bare ground inside and outside exclosures. However, shrub cover in the grazed plots was consistently less than in the ungrazed plots. The cover of *Festuca idahoensis* was higher in grazed plots relative to ungrazed exclosure plots. The addition of a third, 1000 meter sampling plot randomly located in the grazed vegetation confirmed the natural patchiness of vegetation, spatially heterogeneous grazing, selective grazing, and inconsistent responses to grazing.

FIRE

Title: **Fire - A Force for Change and Regeneration in Natural Ecosystems: An Instructional Module**

Principal Investigator: Dr. John Burger
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Objectives: To document long-term changes in Yellowstone landscapes affected by different intensity of fire during 1988, and to develop instructional modules, including a photographic record, explaining the role of fire in the Greater Yellowstone Ecosystem.

Findings: The year 1998 marked the 10th anniversary of the 1988 fires in Yellowstone. Documentation of short and long-term changes in vegetation affected by different fire intensities began in 1990. Observations have concentrated on lodgepole pine, aspen, sagebrush and montane herbaceous vegetation at approximately 20 selected sites, mainly in the northern half of the park. Lodgepole saplings exhibit vigorous growth in most burned areas, and saplings now average 180-240 cm in height. Growth rates averaged 30-60 cm/year in 1997 and 40-70 cm/year in 1998 in most areas. The tallest sapling was found 1 mile south of Norris Junction and was 340 cm tall. Extensive browsing of aspen by elk in the Blacktail area also has been documented. Reproduction in lodgepole saplings was first observed in 1996, eight years post-fire. Saplings examined at the Madison Junction site in 1997 indicated that approximately 5% of the saplings are beginning to produce male and female cones. Lodgepole pines in the Norris Geyser Basin and at the Bunsen Peak site also reproduced at about the same rate in 1997. In most areas, only 3-5% of saplings are producing cones in 1998, but at the Bunsen Peak site, one area had 50% of the saplings producing at least a few male and/or female cones.

Title: **Post-Burn Resource Selection, Physiological Condition, and Demographic Performance of Elk**

Principal Investigator: Dr. Robert Garrott
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Objectives: The primary objective of this research is to evaluate the consequences of the 1988 fires on elk resource selection. Selection is being quantified for populations and individuals at multiple scales ranging from selection of patches within the landscape mosaic to selection of forages and plant parts within patches. The physiological and demographic consequences of observed resource selection strategies are being assessed through noninvasive urinary and fecal assays, and telemetry. Secondary objectives include basic research on forage plant chemical compositions, plant-animal interactions, and applied research to develop practical and rigorous management tools for population monitoring (aerial surveys, fecal steroid pregnancy assays, and snow-urine condition indices).

Findings: We have been successful in developing, testing, and applying a suit of research tools that is significantly enhancing our ability to address questions of animal resource selection and the physiological and demographic consequences of selection patterns. We have completed our seventh field season of data collection and maintain an instrumented population of 30-40 cow elk. Most publications to date have focused on techniques including population estimation, pregnancy assessment, and nutritional indices. We have completed a manuscript analyzing the demographic data thus far collected. Adult survival and reproduction is near the biological maximum for the species, but recruitment is highly variable, being strongly influenced by environmental variation, primarily winter severity. Despite this variable recruitment, extensive Monte Carlo simulations indicate that the population is relatively stable and is being regulated at approximately 600-800 animals. We have generated a database of >7,500 animal locations and are exploring a variety of analytical tools for the analysis of these data. We are also working with USGS/BRD scientists to develop appropriate GIS databases to enhance this analysis effort, and we intend to produce a manuscript based on these data within the next one to two years.

Title: **Landscape Heterogeneity and Bird Diversity under Natural and Human Disturbances in the Greater Yellowstone Ecosystem**

Principal Investigator: Andrew Hansen

See Ecology

Title: **Coarse Woody Debris and Site Productivity in Rocky Mountain Coniferous Forests**

Principal Investigator: Dr. Dennis Knight

See Ecology

Title: **Study of the Effects of the 1988 Wildfire on Yellowstone Stream Ecosystems**

Principal Investigator: Dr. G. Minshall

See Ecology

Title: **Impact of the Fires of 1988**

Principal Investigator: Dr. Daniel Norton

See Geology

Title: **Effects of Fire Size and Severity on Early Succession and Aspen Seedling Establishment**

Principal Investigator: Dr. William Romme

See Ecology

Title: **Postglacial Fire Frequency and its Relation to Long-term Vegetational and Climatic Changes in Yellowstone Park**

Principal Investigator: Dr. Cathy Whitlock
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Objectives: The primary objective has been to study the vegetational history of Yellowstone and its sensitivity to changes in climate and fire frequency. To establish a vegetational history, a network of pollen records, spanning the last 14,000 years, has been studied from different types of vegetation within the park. A reconstruction of past fire frequency is based on information gained from: (a) a study of the depositional processes that incorporate charcoal into lake sediments; (b) a comparison of charcoal and dendrochronologic records of fire occurrence during the last 750 years; and (c) an analysis of charcoal, pollen, and magnetic properties in lake sediment cores spanning the Holocene and late-glacial periods.

Findings: Progress was made on three aspects of this project. First, revision of the Trail Lake record is underway, based on the results of radiocarbon dating and tephra analysis, which indicate that the Trail Lake record is only 8,000 years old. The results of the charcoal, pollen, and magnetic susceptibility analysis using this revised chronology were presented at the 125th Anniversary of Yellowstone National Park Science Workshop in May 1998, sponsored by Yellowstone National Park.

Second, in August we completed analysis of the ninth year of sampling of modern sediments in lakes with watersheds that were burned in 1988. This process-based study provides information necessary to interpret the charcoal record in sediment cores, by determining the time of charcoal accumulation following a fire event. The study is unique, and the results have been used by fire researchers around the world. The samples collected in August 1997 will be evaluated in light of previous results.

Third, we are collaborating with scientists from the US Geological Survey to evaluate the paleolimnologic response of Yellowstone lakes to past climate change. Samples were taken from all the long cores and have been analyzed for sediment geochemistry. Special attention has been directed to northern range lakes, particularly Crevice Lake, which has annually laminated sediments. Water chemistry and temperature measurements were obtained last summer, and plans were made to core Crevice Lake in 2000. The results of the preliminary analysis were presented at the biennial meeting of the American Quaternary Association.

Other accomplishments of note are 1.) The completion of Sarah Millspaugh's dissertation, comparing the Holocene fire history of the Central Plateau and the northern range based on two high-resolution charcoal studies. Chapters of the dissertation have been or will soon be submitted for publication; 2.)

Hosting an international workshop, sponsored by the National Science Foundation and the Inter-American Institute at the University of Oregon in June. (The objective of the workshop was to train other scientists in the methodology of fire history studies based on our experiences in Yellowstone National Park and other regions in the western U.S.); 3.) Preparation of two chapters for a forthcoming book on Fire and Climate in the Western Americas (eds. T.W. Swetnam, T.T. Veblen, and G. Montenegro). One chapter focuses on methodology of lake sediment charcoal studies; the second considers the fire history of Yellowstone and other parts of the western U.S.; 4.) Completion of a chapter on the prehistory of the Rocky Mountains, with an emphasis on the Yellowstone region. Chapter will appear in Rocky Mountain Futures (eds., J.Barron, D. Fagre, R. Hauser); and 5.) Presentation of results at the 125th Anniversary of Yellowstone National Park science meeting in May 1998.

FUNGI

Title:	**Specificity of Ectomycorrhizal Symbioses**
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Additional Investigators:	Sharon Cullings, J.R. Blair, Debie Kinsey, Robert Douglas

Objectives: 1.) To determine whether specificity exists in the ectomycorrhizal community. 2.) To determine effects of disturbance and chemical gradients on ectomycorrhizal community structure and specificity patterns.

Findings: 1.) Specificity exists in old-growth stands: manuscript submitted. 2.) Competition among mycorrhizae of different tree species is important in succession: manuscript submitted. 3.) Soil chemistry changes associated with lower pH of thermally altered soils affect mycorrhizal community structure: manipulation to litter layer and photosynthetic capability of spruce, pine, and fir have been done. Analysis of below ground effects will begin summer 1999.

Title:	**Lichens of Yellowstone National Park. Phase II**
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Additional Investigators:	Clifford Wetmore, Katherine Glew

Objectives: The two objectives of the project were to: 1.) Collect lichen specimens from representative substrates and locations in Yellowstone National Park to establish the lichen flora of the park. 2.)

Collect some lichen specimens for tissue element analysis for air quality information.

Findings: Eversman (1990) reported 186 species of lichens from Yellowstone National Park. The collections from 1998 have yielded about 139 additional species from 49 collection sites. Clifford Wetmore has completed most of his identification of specimens, and Sharon Eversman and Katherine Glew are in the process of identifying and preparing their specimens for herbarium submission. Tissue analysis is complete, but the results are not yet available. The final report is due in June 1999.

Title: **A Survey of *Pilobolus* from Yellowstone National Park**

Principal Investigator: Dr. K. Michael Foos
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Additional Investigators: Dr. Donald Ruch

Objectives: 1.) To obtain isolates of *Pilobolus* to be examined with SEM and TEM to compare spore and sporangia morphology. 2.) To compare isolates from various locations by contrasting morphological characteristics. 3.) To study the characteristics that can be used to identify isolates. 4.) To analyze and compare nucleic acid sequences in the various isolates to compare and contrast taxa. 5.) To analyze and compare cellular short chain fatty acids in the various isolates to compare and contrast taxa.

Findings: Isolates of *Pilobolus* were collected in eleven locations in Yellowstone National Park during 1997. These isolates were collected from mule deer, buffalo, and elk. They were collected from areas near Grant Village, Duck Lake, Hayden Valley, and Mammoth Hot Springs. All isolates have been maintained in the laboratory at Indiana University East and are being used as part of a larger experiment to distinguish among the species of Pilobolus.

Isolates of Pilobolus were collected in twenty-two locations in Yellowstone National Park during 1998. These isolates were collected from mule deer, buffalo, pronghorn, and elk. They were collected from areas near Grant Village, Indian Creek, Canyon, Hayden Valley, and Mammoth Hot Springs. All isolates have been maintained in the laboratory at Indiana University East and are being used as part of a larger experiment to distinguish among the species of *Pilobolus*.

It should be noted that *Pilobolus* does not survive well under cultivation. Most isolates of *Pilobolus* collected in earlier years have died.

Title: **Investigation of Fungal Detection and Remediation of a Biological Pathogen**

Principal Investigator: Dr. Susan Thomas
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Additional Investigators: Dr. Peter Becker, Paul Stamets

Objectives: To collect, identify, culture, and engineer through preconditioning methods certain fungal strains to apply to detection and remediation of the pathogen, *Brucella abortus*. A single field collection in Yellowstone was necessary for the project; it was carried out October 15-20, 1998.

Findings: To date, we have identified and cultured the fungal species collected onsite in Yellowstone. We have completed preliminary screening tests, and we are preconditioning several strains for the next series of screening tests. Henceforward, all of our work will be in the laboratory.

Title: **Fungi from Geothermal Soils and Thermotolerant Plants**

Principal Investigator: Dr. Rusty Rodriguez

See Microbiology

GEOLOGY

Title: **Dendrochronology in the Yellowstone Fossil Forest**

Principal Investigator: Dr. Michael Arct
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Objectives: Map petrified wood localities and interpret ecological and depositional histories of various fossil forests using: 1.) Annual growth ring series (crossidentification, standard descriptive statistics, tree age determinations); 2.) Taxonomy; 3.) Taphonomy; and 4.) Rock descriptions. Most recently, attempts have been made to use botanical features from specific horizons at the Specimen Creek locality to determine stratigraphically equivalent horizons at an exposure 1.3 km to the southeast.

Findings: Fieldwork was conducted at the Specimen Creek exposure. Data as previously described was recorded on 71 fossil stumps. No specimens were collected. One stump displaying apparently in situ root growth along the face of a rock was photographed.

Title: **Investigation of CO_2 Emissions Related to the Yellowstone Volcanic/Hydrothermal System**

Principal Investigator: Dr. Susan Brantley
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Additional Investigators: Cindy Werner

Objectives: 1.) To estimate the CO_2 emissions due to the Yellowstone volcanic/ hydrothermal system. 2.) To monitor background temporal variability of CO_2 emissions, and how variations are related to changes in hydrothermal and seismic activity. 3.) To study the spatial distribution of CO_2 emissions and investigate controls on spatial heterogeneity of gas emissions; and 4.) To monitor gas chemistry including carbon and helium isotopes to gain a broader understanding of the sources of magmatic gases and interactions with the hydrothermal system.

Findings: During the summer of 1997, extensive flux measurements were completed in the Mud Volcano thermal area. A statistical sampling plan was implemented in order to measure a statistically valid flux for the area, and in order to better understand spatial heterogeneity in the park and in that area in particular. Using the statistical sampling plan to estimate an overall CO_2 flux from the whole Mud Volcano area yielded an estimate of 10^9 mol CO_2 /year as a time-averaged flux. Using heat flow estimates for the whole park we also estimated, based upon our summer work in Mud Volcano, that the total CO_2 flux parkwide could be as large as 10^{12} mol CO_2/y. This value, roughly equivalent to 10-20 average coal-burning power plants, is a large flux compared to most volcanoes. The largest flux ever measured at a volcano is the flux measured at Etna (Italy, 1 x 10^{12} mol CO_2 /y), and thus, if our estimate for the park is correct, this suggests that park carbon emissions may be a significant contributor to volcanic/geothermal emissions of CO_2 worldwide. More measurements are needed to confirm this hypothesis.

In 1998, a stratified-adaptive sampling plan was designed to estimate CO_2 degassing in Yellowstone National Park, and applied in the Mud Volcano thermal area. The stratified component focused effort in regions with the most spatial heterogeneity (high-flux regions), without biasing our estimate for the total region. The maximum and minimum measurements for vent and diffuse fluxes were 2.4 x 10^9 and 6.3 x10^4 mols/ yr, and 32,000 and 4.0 g/m^2 day, respectively. Fluxes observed in most vegetated regions of Mud Volcano were similar to values reported by agricultural studies (<38 g CO_2/m^2 day). However, we also found a few high-flux vegetated sites (up to 5,000 g/m^2 day) that are likely thermal features that have waned in thermal activity, yet are preferred pathways for degassing of deep CO_2. Vent degassing (2.4 x 10^9 mols/yr) accounts for ~50% of the total degassing observed at Mud Volcano (4.9 x 10^9 mols/yr). Using estimates of magma emplacement rates from other studies, we calculated a rough CO_2 flux for the entire Yellowstone system based on the relationship between heat flux and CO_2 degassing. We approximated an emission rate of 7 x 10^{11} mols/yr, which is comparable to globally important volcanic fluxes.

Temporal variation of CO_2 emissions was observed to correlate with soil moisture and environmental conditions. Preliminary investigation of the CO_2 emissions in the Upper Geyser Basin, Mammoth Springs, Roaring Mtn., Washburn Springs, Crater Hills, and the Lamar River Valley suggest that diffuse degassing is highest in acid-sulfate and travertine precipitating regions, and lowest in regions of silica precipitation and sulfur flows. No attempt has been made to estimate vent emissions in these areas.

Title: **Recognizing the Signatures of Hyperthermophilic Biofilms: Geyserite, Epithermal Deposits, and Ancient Cherts**

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Additional Investigators: Dr. David J. DesMarais

Objectives: Our primary objective is to establish criteria that will facilitate the recognition of ancient geyserite stromatolites and subsurface hydrothermal deposits that formed in the presence of hyperthermophilic biofilms. Our approach is to characterize the biogeochemical signatures of modern hyperthermophilic communities using a combination of field, experimental, and analytical techniques (i.e., molecular phylogeny in collaboration with N.R. Pace and co-workers, electron beam ultrastructural analysis, quantitative mineralogy and petrography, and isotopic and biomarker compound analysis). By studying how modern hyperthermophilic ecosystems are converted to their paleobiological counterparts, we can identify the processes responsible for the preservation of microfossils, chemofossils, and sinter stromatolites.

Identify the processes by which hyperthermophilic biosignatures are preserved in the rock record requires understanding of mechanisms of initial preservation and subsequent diagenetic alternation. Our goal is to establish a framework within which the paleobiology of hyperthermophilic communities fossilized in hydrothermal sinter and epithermal deposits can be identified and properly interpreted.

Findings: In 1997, we found that hyperthermophilic biofilms are distributed on the sediment that accumulates at the bottoms of thermal spring pools and on the surfaces of permanently submerged geyserites and geyserites that occur in periodically submerged splash zones around thermal springs. Scanning electron microscopy (SEM) analysis reveals that in each of these types of microenvironments, the biofilms are composed primarily of filamentous hyperthermophiles surrounded by a polysaccharide matrix. SEM images show that filamentous biofilms (< 1 micron thick) display different architectures that can be correlated with the specific hydrodynamic conditions of the microenvironment. Having characterized the distribution and ultrastructural characteristics of hyperthermophilic biofilms within Octopus Spring, we plan in the coming year to compare hyperthermophilic biofilms from a variety of geochemically diverse thermal springs. Additional electron microscopy analysis indicates that the fidelity of microfossil preservation depends upon the fossilization mechanism, and on the environmental conditions within which silicification occurs. Our current aim is to identify the exact mechanisms that enhance microfossil and stromatolite preservation in thermal spring and geyserite deposits located

within Yellowstone National Park, Wyoming.

In 1998, we identified members of hyperthermophilic microbial populations found in silica-depositing springs using molecular phylogeny and various microscopy methods (optical, scanning and transmission electron microscopy). We characterized distribution of hyperthermophilies on natural sinters and on various substrates within different microenvironments (subaqueous and subaerial) of several pools. We also characterized the biogeographic distribution of dominant community members for several silica-depositing springs located in different thermal basins using molecular phylogenetic analysis.

Title: **Relationship Between the Geochemistry of the Waters and the Geochemistry and Petrography of the Precipitates Within Hot Water Travertine Systems**

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Additional Investigators: Sean A. Guidry

Objectives: The primary objectives of this investigation are to analyze the water-carbonate precipitate relationships within hot water travertine systems and the water silica relationships within some of the silica rich systems. More specifically, the goal is to delineate the mineral species, individual crystal habits, morphologies of crystal habits, and the elemental and stable isotopic composition of the solids that precipitate within the waters of a variety of travertine and geyserite systems. In addition, we are studying the microbial community and its relationship to the mineral precipitates. We are concerned with the preservation of microbes in these systems and the ability to recognize their remains with increasing alteration of the mineral precipitate. Of particular interest is whether the microbes impart a recognizable geochemical signature to the mineral precipitates. Another area being emphasized is the search for and significance of nanobacteria within the system.

Findings: Analyses to date strongly indicate that there are significant constraints on the use of geochemical signatures to indicate the paleoenvironmental conditions at the time of travertine precipitation (Chafetz and Lawrence, 1994). The composition of the waters change temporally and laterally within individual travertine systems. These findings have been substantiated with analyses of water and precipitates from other hot spring systems. Analogous analyses of siliceous systems are in progress. Microbial organisms actively promote travertine precipitation in addition to acting as an important substrate for nucleation and crystal growth. Study of the preservation of the microbes is in progress.

Title: **Geochemical Baselines in the Greater Yellowstone Area**

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Additional Investigators: Robert C. Carlson, William Miller, Harley King, Richard Sanzolone

Objectives: 1.) Provide objective, unbiased geochemical baseline data for about 50 chemical elements determined in samples of rock, active stream-sediment, water, plants, and animal scat collected from scattered localities throughout Yellowstone National Park (YNP) and the adjacent U.S. Forest Service lands. Baselines to include raw data and interpretive report. 2.) Identify the sources of anomalous concentrations of selected elements, such as geothermal features, past mining, and recreation. 3.) Determine the chemistry of selected elements in the food chain and how these elements may impact the health of wildlife in the park.

Findings: Samples of stream sediment, rock, water, and/or animal scat have been collected from as many as 330 sites (136 sites in 1998) in and around YNP. These samples have been analyzed for as many as 50 elements. In the northeastern part of the park, weakly anomalous levels of elements related to mineralized rock or to past mining in the Cooke City area have been detected in samples from the Soda Butte Creek drainage basin. These weak anomalies extend to the confluence of Soda Butte Creek with the Lamar River, where sediments from that stream with background levels dilute the anomalous concentrations from Soda Butte Creek to background levels.

In the geothermal areas of the park studied to date (both fossil and active), a common suite of elements are generally present in sediment downstream from each locality. Concentrations for some elements, such as arsenic and fluorine, are significantly elevated as compared to background levels.

Analysis of elk and bison scat shows anomalous concentrations of elements associated with geothermal features for those animals grazing near such features, indicating that animals living in geothermal areas are ingesting significant levels of elements such as arsenic and fluorine. The effects of fluorine on elk have been documented by others. The effects of other elements on elk or other animals are not known.

Sampling is continuing to better define and understand the sources of anomalies.

Title: **Volcanology and Petrology of the Yellowstone Plateau Volcanic Field**

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Additional Investigators: Wes Hildreth

Objectives: To understand the origins and eruptive mechanisms of late Cenozoic volcanic activity in the region of Yellowstone National Park, and to complete systematic geologic-mapping studies carried out intermittently in the park region since the 1960s.

Findings: No new work was done on this project in 1998. USGS Professional Paper 729-G is now nearly ready for publication by the USGS Western Publications Group, awaiting only final digital details on the largest geologic-map plate.

Title: **Mapping the Mineralogy Vegetation and Microbiota of Yellowstone National Park Using Imaging Spectroscopy**

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Objectives: This task uses remote data gathered by an airborne spectrometer to map the distribution of minerals, vegetation cover types, and thermophilic bacteria in selected areas of Yellowstone National Park. The derived maps are analyzed for the surficial expression of underlying geologic processes and the geologic controls on vegetation distribution. The task objectives are: 1.) Use the spectroscopic remote sensing data to map the distribution of minerals within the covered areas of the park and relate their presence to the geologic processes leading to their formation. 2.) Use spectroscopic remote sensing data to map the distribution of biologic materials and examine the relationships between geologic controls on biologic cover.

Findings: This task uses remote sensing data gathered by an airborne spectrometer to map the distribution of minerals, vegetation cover types and thermophilic bacteria in selected areas of Yellowstone National Park. The remote sensing data was collected by the Airborne Visible and Infra-Red Imaging Spectrometer (AVIRIS) at 17 meter resolution in 1996 and at higher spatial resolution in 1998 (approximately at 1.6 meter pixel size). Initial mapping has been completed using 17 m data for minerals and vegetation cover types. The 1996 AVIRIS data was also used to detect the presence of microorganisms growing in the heated water flowing out of the park's hydrothermal geysers and pools. High spatial resolution data has been examined in a preliminary manner. A compositional comparison of the higher spatial resolution data with the lower spatial resolution data show good agreement between the minerals detected from each flight. The minerals detected indicated the type of alteration occurring in the various geyser basins of Yellowstone National Park. The variety of alteration minerals occurring within the areas of the park covered by the airborne spectrometer indicate differences in the pH and temperature of hydrothermal fluids. The high-resolution data reveal even finer details of the distribution of alteration minerals within the basins. The high-resolution data collected in 1998 show a greater variation in reflectance signatures from bacterial mats, indicating that the possibility of mapping bacterial species of bacterial mat composition from such data. Vegetation maps of forest and non-forest cover types derived from AVIRIS 1996 data have been developed. For FY00, the proposed work includes final stages of field verification of maps of materials derived from the AVIRIS 1996 data. In addition, material maps for two selected areas will be derived from the high spatial resolution data (Old Faithful and the Norris Geyser Basin/Roaring Mountain). Publication of existing draft manuscripts is expected to be completed. Georectification of imagery will be performed in order to produce material maps that can be provided directly to the National Park Service and the general public through the Internet. Finally, maps of biologic materials will be compared with existing geologic information in order to examine the influences of underlying geology on the park's vegetation cover.

Title: **Investigations of Sediments of Lakes in Yellowstone National Park for Records of Past Climate and Environmental Change**

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Additional Investigators: Cathy Whitlock

Objectives: Investigate past changes in climate and environments in Yellowstone National Park based on geochemical, mineralogical, and biogenic components of lake sediments.

Findings: Samples were collected at 10 cm intervals from four long cores, and eight short (surface-sediment) cores by Cathy Whitlock, University of Oregon, for pollen and fire-history investigations. The long cores are from Cygnet Lake, Trail Lake, Slough Creek Pond, and Blacktail Fen. The short cores are from Cascade Lake, Dryad Lake, Duck Lake, Goose Lake, Grizzly Lake, Lake of the Woods, Sylvan Lake, and Wrangler Lake. Concentrations of organic carbon (OC) and calcium carbonate ($CaCO_3$) were measured in all samples from all cores. Only sediments from lakes in the northern range of the park (Blacktail Fen and Slough Creek Pond) contain measurable amounts of$CaCO_3$. The $CaCO_3$ contents of sediments in Blacktail Fen have remained high (50-75%) throughout its history as an open lake and, most recently, as a wetland. The OC contents of sediments in Blacktail Fen have fluctuated considerably throughout its history. The core has not yet been dated by radiocarbon methods, but contents of both $CaCO_3$ and OC were much more variable in the lower half (4-7 m) of the core suggesting that environmental conditions in the lake, and perhaps climatic conditions in the area of the park, were much more variable during the early history of the lake. Both parameters are much less variable in the upper three meters of the core. The $CaCO_3$ contents of sediments in Slough Creek Pond are lower, and contents of OC higher, than in sediments from Blacktail Fen. The $CaCO_3$ content in the lower two meters of the core from Slough Creek Pond are slightly higher (30-40%) than in the upper two meters (20-30%). The OC content increased steadily throughout the history of Slough Creek Pond, from <5% at the base of the core to 20% at the top. The OC content of sediments in Cygnet Lake increased dramatically about 9,000 years ago, from <4% to more than 15%, then decreased slowly to about 10% at the top of the core. The OC content of sediments in Trail Lake increased slowly but steadily from <2% at the base of the core to about 15% at the top. The OC content of surface sediments in the eight lakes sampled ranged from a low of 6.3% in Duck Lake, to a high of 23.1% in Wrangler Lake, with an average of about 10%.

The organic matter in sediments from Slough Creek Pond and Trail Lake, at opposite ends of the park and in very different geologic, hydrologic, physiographic, and climatic settings, was analyzed by Rock-Eval pyrolysis. This technique measures a hydrogen index and oxygen index that can be used to distinguish hydrogen-rich, oxygen poor algal organic matter from hydrogen-poor, oxygen-rich terrestrial organic matter. The results show that the organic matter in sediments in both lakes is almost entirely algal, that is, produced in the lake. This conclusion was further substantiated by the carbon and nitrogen-isotopic composition of the organic matter. Isotopic analyses have been completed on most samples and indicate that the organic matter in sediments from the other lakes, like that in Slough Creek Pond and Trail Lake, is of algal origin.

Because the waters of Blacktail Fen and Slough Creek Pond are carbonate-rich, both of these lakes have always had a rich mollusc fauna (snails and clams). The carbon and oxygen-isotopic composition of the $CaCO_3$ in the shells of these molluscs can provide valuable information about changes in salinity and hydrology of the lake, and of sources of organic matter and changes in productivity in the lake. The isotope analyses are currently in progress and should be completed by the summer of 1998. Mineralogical analyses by X-ray diffraction also are in progress and should be completed by this summer.

Title: **The Silicification of Plants in Hot Springs, Yellowstone National Park**

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Additional Investigators: Alan Channing

Objectives: 1.) Assess the possible environments of higher plant silicification, burial, and diagenetic alteration associated with surface geothermal activity. 2.) Investigate the extent and nature of silica mineralization within plant material of hot spring environments. 3.) Determine physicochemical, biochemical, and physiological controls on silica permineralization at cellular to structural levels. 4.) Compare silica fabrics from Yellowstone plants, sub-fossils, and fossils with those of a 400 million year old fossil hot spring deposit at Rhynie, Aberdeenshire, Scotland. 5.) Investigate the physiological adaptations of modern plants to the sedimentary, hydrogeological, and geochemical regimes of modern hot springs, and assess the probability of similar adaptive strategies in early terrestrial ecosystems.

Findings: 1.) SEM observation of plant material displaying incipient silica mineralisation provides evidence of intracellular nucleation, polymerisation, and aggregation of sub-micron spheres via colloidal mechanisms. 2.) Silica deposition fabrics and the degradation of plant materials are mediated by the interplay between a suite of physicochemical parameters notably pH, temperature and cation concentration. 3.) Rapid vertical, lateral and temporal variation in substrate/groundwater temperature, moisture, and geochemistry indicate a degree of tolerance to those conditions in colonizing plants. Xerophytes, halophytes, and aquatics occupy and are silicified within definable hot spring sedimentary facies. 4.) Light microscopy reveals evidence of "ghost" microspheres in cell lumens of Rhynie plants. XRD analysis of picked intracellular separates indicate the dominance of non-crystalline silica phases in initial cellular permineralisation. Microcrystalline silica phases dominate Rhynie material. Cell function, particularly as it relates to cell wall thickness and stability of component organic compounds in hydrothermal fluids, greatly influences the degree of cellular and structural replication/preservation during permineralisation.

Title: **Biosedimentology, Microbiology, and Geochemistry of Modern Hot Springs**

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Objectives: To understand basic fossilization processes in subaerial thermal springs over a range of conditions in temperature, pH, composition, etc., and to observe the effects of early diagenesis on the biosignatures captured with sinter deposits.

Findings: To date we have established a basic observational database that reveals the types of preservation (microbial fossils) occuring in siliceous, travertine, and Fe-oxide precipitating springs, and the transistional record of deposits that have undergone initial diagenesis.

Title: **Geochemistry and Geochronology of Eocene Potassic Volcanism in the Absaroka Volcanic Field**

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Objectives: Our objective is to carry out a geological and geochemical transect across the northern part of the Eocene Absaroka volcanic field. Because the Absaroka volcanic rocks record one of the most voluminous and compositionally diverse magmatic episodes to affect the Cordillera during the Eocene, the results obtained from this study will improve our knowledge of the ages, compositions, and petrogenesis of Tertiary magmatism in the northern Rocky Mountains. This, in turn, will provide insight into the fundamental problem of how rock suites with arc-like geochemical features can form in such different tectonic environments, and possibly in the absence of contemporaneous subduction. The

targeted areas in Yellowstone National Park are the Mt. Washburn-Observation Peak volcanic center, the Sepulcher Mountain-Electric Peak eruptive center, and the Sylvan Pass-Eagle Peak eruptive center.

Findings: To date we have collected approximately 90 fist sized rock specimens from the targeted localities in Yellowstone National Park. Most of these have been cut for thin sections and analyzed for major and trace element contents. Currently, about 15 samples are awaiting $^{40}Ar/^{39}Ar$ age determinations, which should be completed by the end of summer 1999. Further, about 25 samples are currently awaiting analyses for Sr, Nd, and Pb isotopic ratios, which should also be completed this summer. In conjunction with samples from outside of the park, we have found that there appears to be no systematic relationships between geographic position of Absaroka eruptive centers with geochemical indicators of subduction-derived fluids. Whereas all samples have high values for ratios commonly associated with subduction zones (e.g., Ba/Nb), samples from centers to the east of the park (and presumably east of the Eocene oceanic trench) have the highest values. This is inconsistent with smaller degrees of volatile fluxing to the east. Thus, the Absaroka volcanic field may have a more complex origin than a simple subduction related volcanic arc.

Title: **Crustal Structure and Composition of Yellowstone National Park and their Relation to Hydrothermal and Seismic Activity**

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Objectives: The objective was to collect aeromagnetic data along east-west lines spaced 400 m apart at an elevation 700 ft. above the terrain in order to delineate faults, alteration that might record fossil hydrothermal activity, volcanic flows, and sedimentary basins in YNP.

Findings: Unmapped faults within the caldera, that might represent the ring fracture system that localized lava flows and might be associated with hydrothermal explosion craters, have been delineated. It is not clear whether they are seismically active. Alteration associated with the major hydrothermal systems, as well as in Yellowstone Lake, have been identified. Combination of the aeromagnetic data with geologic, geochemical, and remote sensing data will help delineate lava flows and fossil hydrothermal systems. This analysis will help provide a clearer picture of the history of hydrothermal activity in the park.

Title: **Geology and Chemistry of Hot Spring Deposits**

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Additional Investigators: Dr. Joseph Moore, Dr. Roy Mink

Objectives: To characterize the geologic and geochemical environments of hot spring deposits in Yellowstone National Park.

Findings: Collecting was carried out in 1997 at Calcite Hot Springs. During 1998, a report titled "Chemical Analyses of Geologic Samples: Calcite Hot Springs, Yellowstone National Park," was submitted to Yellowstone. This report, by Andrew L. Glandon, was prepared as a senior capstone research project at Pacific Lutheran University. SEM and ICP data were collected, but further chemical analyses are required before definitive conclusions can be reached about the deposits of this fascinating site.

Samples collected are stored in the Department of Geosciences at Pacific Lutheran University.

Title: **Aqueous Geochemistry and Sediment Mineralogy of Selected Hot Springs, Yellowstone National Park**

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Objectives: 1.) To add to an existing data base of geochemical analyses of Yellowstone thermal features. 2.) To increase our knowledge of the mineralogy of hot spring sediments, with a focus on the clay rich deposits. 3.) To increase our understanding of the thermodynamics of clay mineral formation at the earth's surface.

Findings: Field data, sediment, and water samples were collected from hot springs and mud pots in the Mud Volcano, Norris Basin, Midway Basin-Rabbit Creek, Clear Water Springs, and Artist Paint Pots

geothermal areas. Field measurements were made at 56 sites and included pH, temperature, conductivity, and oxygen reduction potential (ORP). GPS readings for each site were made by an SCA volunteer (S. Miller) under the direction of Ann Rodman. 29 water samples were collected and analyzed for total dissolved solids (TDS), H_2S, HCO_3, CO_3, Cl, SO_4, K, Na, Mn, Fe, Al, Mg, Ca, Li, SiO_2. X-ray diffraction analysis of 20 suspended sediment samples is in progress.

Title: **Interpretation of the Geochemistry of Thermal Waters (Old U.S.G.S. Project 9980-00292, Hydrothermal Fluids)**

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Objectives: 1.) To characterize the chemical and isotopic nature of the Yellowstone hydrothermal system. 2.) To gain an understanding of the evolution of this hydrothermal system and how it interacts with its magmatic heat source. 3.) To monitor possible chemical and physical changes in the hydrothermal activity.

Findings: We found a significant change in pH and sulfate, but not chloride, in waters from Sulfur Dust Spring over a three week period a few weeks before the start of the yearly hydrothermal disturbance [1995]. There was no detectable change in the composition of Sulfur Dust water during the disturbance. These observations may be important for gaining an understanding of the origin of the acid-chloride-sulfate waters at Norris. This type of water is absent in Upper and Lower Geyser Basins.

The project leader retired from the USGS in 1997 and the project was inactive in 1998. The project is not likely to be active in 1999. It would only become active in the event of some major geologic event that impacts the physical and chemical nature of the hydrothermal activity. R. Fournier is available to consult with other researchers about their research activities involving the Yellowstone hydrothermal activity.

Title: **Monitoring of Thermal Chloride Flux in Yellowstone National Park**

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Additional Investigators: Daniel R. Norton

Objectives: 1.) Monitoring of chloride flux, which is a proxy for heat flow from the magma underlying Yellowstone. 2.) To detect adverse changes in the thermal system due to proposed development of geothermal, gas, and oil resources adjacent to the park. 3.) To secure baseline data related to changes in the geothermal system caused by earthquakes and other tectonic events. Monitoring includes the total chloride flux as measured in the four rivers draining the park, as well as chloride flux from major thermal areas within the park.

Findings: We have secured a database from 1983 to the present (1998). Variations in chloride flux are related to discharge of the four rivers, which in turn, is related to precipitation in the park.

Title: **Analysis of Obsidian in the Northwestern USA**

Principal Investigator: Michael D. Glascock

See Archeology

Title: **A Petrological and Geochemical Analysis of the Tanker Curve Obsidian**

Principal Investigator: David Hansen

See Archeology

Title: **Geochemistry of Hot Spring Sinters and Microbial Mats**

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Additional Investigators: Cindy Wilson, Jenni DeMonge, Treavor Kendal

Objectives: 1.) Investigate geochemical variations in microbial mats, pore waters, siliceous sinters, and geyserites at different hot springs and thermal drainages in the park. Results will be compared with stage of silica diagenesis and geochemistry. 2.) Investigate the local hydrogeological characteristics of hot spring-influenced drainages. Results will be used to calculate mass balances for such drainages, to determine silica deposition rates in sinter mounds, and to determine interaction with local groundwater. 3.) Investigate seasonal changes in microbial communities and accompanying silica deposition rates.

Findings: Field work conducted during summer 1997 focused on confirming results from previous sampling periods on the diel changes in thermal springs, on continued monitoring of chemical and hydrogeological parameters in thermal drainages, and on evaluating the quality of data collected in previous work through comparison with other laboratories.

Diel Cycling of Chemical Parameters in Thermal Springs: Sampling at Chocolate Pots was conducted for a period of 48 hours during June 1997. Samples were collected hourly with a modified collection technique. The new collection procedure successfully prevented changes in component speciation providing more accurate results. In addition, a new, smaller pore size filter was used to better exclude colloidal and fine particulate material. Parameters measured were the same as previous sampling periods with one exception: ferrous and total iron concentrations, pH, dissolved oxygen, temperature, cation concentrations, and anion concentrations. Hydrogen peroxide was not measured.

Results failed to confirm diel cycling in ferrous iron concentrations at the Chocolate Pots vent, however cycling was observed to a limited extent distal from the vent. The lack of cycling at the vent suggests that the new, smaller filter size excludes particulate matter which had previously contributed to cycling of the ferrous and total iron concentrations. These results are consistent with published results on the concentrations of ferrous and total iron at the vent. Interestingly, a change is observed in the percent distribution of iron species at the distal sites. Ferric iron concentrations increase, even in the dissolved fraction, during daylight hours, driving cycling of total iron concentrations. The observed fluctuations are correlated with fluctuations in pH and dissolved oxygen.

Monitoring of Thermal Spring Chemistry: Octopus Spring, the site of ongoing hydrochemical and hydrogeological monitoring, was sampled in June and July of 1997. In addition, the piezometers around

Octopus Spring were sampled in July of 1997.

Field work conducted during summer 1998 focused on processes of silica accumulation in thermal springs and drainages, on identification of chemical and hydrogeological parameters identifying the sequence of deposition of these siliceous deposits, and the factors controlling diel variations in the chemistry of thermal springs. All samples collected not consumed during analysis are housed at the University of Montana. Specific results follow.

1.) Interaction of Thermal Spring Runoff with Shallow Groundwater and with Surface Water: Unlike surface runoff from thermal springs, subsurface runoff is not easily traced, yet is of ecological and managerial importance. In Yellowstone National Park, several streams drain thermal areas combining meteoric runoff with thermal runoff. Within the thermal runoff channels themselves, mineral precipitation removes components that become oversaturated upon cooling, leaving behind soluble components or those whose precipitation is kinetically inhibited. This modified runoff seeps into shallow groundwater resulting in further chemical modifications and mineral precipitation. Numerous stretches of Yellowstone streams are armored, including sporadic areas of Nez Perce Creek, Sentinel Creek, and Iron Spring Creek, as well as large portions of the Firehole River. Streambed armoring is evidenced by streambed sediments cemented in place by a gray-colored matrix; it is easily distinguished from the in-stream sinter deposits formed when surface thermal features drain into the river. Stream chemistry and nutrient cycling are impacted because the armoring forms an impermeable barrier along the streambed. Ground water and surface water samples were collected monthly and analyzed for major anions, major cations, and dissolved organic carbon (DOC). Temperature, dissolved oxygen, and pH were measured at each site. Initial results show lower DOC, fluoride, chloride, nitrate, and sulfate concentrations in surface water than in ground water. Streambed armoring is most likely caused by silica precipitation at the ground water-surface water interface.

2.) Silica Accumulation in Thermal Springs: Silica accumulation was studied in three outcrops of siliceous sinter. Results indicate that there are distinctive characteristics for each type of silica accumulating within sinters. Significant differences are noted among primary silica, cements found in microbially-textured sinters, and cements associated with breccias. The cause of these differences is under investigation.

3.) Studies into factors controlling diel cycling in thermal spring waters focused on hydrogen peroxide formation and decay. Results indicate that the formation is abiotically controlled by oxidation-reduction reactions involving iron. Decay is controlled by microbial processes. These results are exciting because they demonstrate a link between largely abiotic processes and biological processes.

Title: **Geochemistry and Geochronology of Eocene Absaroka Volcanism**

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Additional Investigators: Lawrence Snee, Anita Grunder

Objectives: To establish the petrogenetic history of the Absaroka Volcanic Province, by establishing the sequence of eruptive activity, and the major, trace element and isotopic variability of eruptive products. Age determinations by $^{40}Ar/^{39}Ar$ isotopic dating on ash-flow tuffs will provide regional age relationships, while ages from individual volcanic centers will link regional and local eruptive activity. Multi-elemental geochemical analysis will be used for geochemical modeling, to determine why and where melting (magmatism) occurred, and the relative contributions of crust, mantle, and asthenosphere.

Findings: Several ash-flow tuff deposits, presumed to be separate events, have been correlated, establishing age relationships of volcanic deposits in Yellowstone to the surrounding region, and providing a greater appreciation to the brief period when most of the middle Eocene volcanism occurred. Regional tuff deposits exhibit a north to south age relationship, the Slough Creek Tuff in northern Yellowstone erupted 49.5 Ma (million years ago), Pacific Creek and Slough Creek tuff (now correlated) erupted 48.8 Ma, and Two Ocean ash-fall erupted 47.5 Ma. The age of the Two Ocean ash-fall allows its correlation with the Blue Point ash-fall, a regional stratigraphic marker which has been established in the region surrounding Yellowstone. Newly established age relationships provide the information necessary to significantly revise the stratigraphy of the Absaroka Volcanic Province in Yellowstone. The oldest eruptions occurred in northern Yellowstone 53 Ma. Most of the eruptive activity took place between 49.5 and 47.5 million years ago, and the youngest volcanic deposits of this period are found on Two Ocean and Trident. Age relationships also indicate that a period of uplift and erosion during volcanic activity occurred about 48 million years ago. Geochemical analyses of samples from individual volcanic centers, observed in conjunction with geological features indicate that volcanism was produced during a period of extension. Melting is primarily derived from the lithospheric mantle with a minor amount of magma contributed from the asthenosphere. As magmatism progressed, contamination and derivation of magma from crustal and lower crustal sources occurred. Mafic (<53% SiO_2) lavas are highly potassic and occur throughout the province. Although more contaminated lavas are superficially similar to those produced in a subduction environment, mafic lavas have major and trace element chemistry, which are characteristic of within plate basalts produced in an extensional environment. Structural features produced by crustal extension during the Eocene are common features, including detachment faults in the Absaroka Province. Study and isotopic dating of dikes and intrusions cross-cutting a detatchment surface is also underway and provide an irrefutable link

between the age of volcanism and local extension.

Title: **The Study of Siliceous Deposits in Geothermal Areas, USA & Japan**

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Additional Investigators: E. Izawa, S. Ogata

Objectives: This study, which concluded in mid-1998, was aimed at comparing the morphology, structuring, and formation of siliceous sinter around hot springs in YNP and Japan.

Findings: The results included the careful study of a 500,000 year old sinter deposit, called the Ikiryu Sinter, on the island of Kyushu, Japan; examination of sinters deposited at several geothermal power plants on Kyushu; and examination of modern sinters on Kyushu and northern Honshu. In addition, Japanese scientists made visits to YNP in the summers of 1996 and 1997. The Ikiryu sinter contains abundant, well-preserved bacterial structures that allow a thermal zonation of the sinter deposits.

Title: **The Structure, Facies, and Deposition of Siliceous Sinter around Thermal Springs: Implications for the Recognition of Early Life on Earth and Mars**

Additional Investigators: Deena Braunstein

Objectives: 1.) To study the textures and structuring of siliceous sinters deposited around hot springs and to determine the physical and chemical controls on sinter deposition. 2.) To characterize the role of thermophilic organisms in sinter deposition. 3.) To compare the structure of sinter with that of putative biological structures in the oldest sedimentary rocks on Earth. 4.) To evaluate which features of sinter are diagnostic of biological influences to aid in possible identification of organisms during planetary exploration.

Findings: Our investigations to date have focused on the hydrodynamic controls on the structuring and morphology of siliceous sinter facies around alkaline hot springs and geysers in Yellowstone. Our work can be divided into 2 substudies: 1.) an investigation of low-temperature (<73 degrees C) sinter facies, where cyanobacterial mats play a significant role in the structuring and development of sinter at all

observational levels; and 2.) an investigation of high-temperature (>73 degrees C) sinter facies where thermophilic bacteria may play a role in mediating silica precipitation rates and influence microstructuring and microtextures, but where hydrodynamics are the primary control on the development of sinter macrostructures. Ph.D. student Deena Braunstein continued her fieldwork studying high-temperature sinter in Yellowstone, making one trip to the park in September 1998. She gathered additional data on the hydrodynamic behavior and structuring and morphology of siliceous sinter deposited around a variety of alkaline siliceous hot springs and geysers. This information has been used to define and characterize a variety of hot spring "types". The relationship between hot spring and geyser hydrodynamics and the morphology and structuring of associated siliceous sinter is the subject of the first chapter in her doctoral thesis. In addition, she collected sinter growth experiments started in 1996 and 1997.

Dr. Lowe continued his investigations at Steep Cone Spring, which has been a site of detailed photo-documentation of sinter growth rates for several years. In addition, growth-rate experiments were collected from the Buffalo Pool Group and Five Sisters Springs, and new experiments were installed at these sites and in Coral Pool in Shoshone Geyser Basin.

Findings: We have classified a limited suite of alkaline siliceous hot spring types, based on hydrodynamics and sinter morphology: 1.) non-boiling springs, including non-surging and gently surging springs; 2.) boiling springs, including non-surging and strongly surging springs; and 3.) geysers, including sputtering, fountain and cone types. The primary hydrodynamic factors include: degree of submergence, convection and discharge related circulation, surging (i.e., periodic water level fluctuations), wave activity and splash, and eruption frequency. Our results continue to emphasize that hydrodynamics play the primary role in high temperature sinter development in that it ultimately controls wetting/drying locations and rates, and thus, silica precipitation. Although benthic bacterial biofilms are widely if not ubiquitously present in subaqueous and splash zones, their influence on sinter deposition and macroscopic structuring remains uncertain.

Title: **Volcano Emissions**

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Additional Investigators: Dr. Terrence Gerlach, Mr. Michael Doukas

Objectives: Survey and characterize carbon dioxide emissions from Yellowstone soils and thermal areas

in order to identify possible areas of anomalous degassing from depth, and to provide a baseline with which to compare future surveys of carbon dioxide in the event of volcanic unrest. The study involves airborne measurements of carbon dioxide and other gases in the air above the park, as well as ground measurements of carbon dioxide soil efflux within the park.

Findings: Several areas of carbon dioxide efflux have been measured within the park that are greater than what would be expected from normal biologic activity in the soil. In addition, several carbon dioxide plumes from various sources within Yellowstone were successfully measured in the air above the park in 1998 utilizing sensitive instrumentation mounted in fixed-wing aircraft. The detailed analysis of data is not yet complete.

Title: **Holocene and Modern Geomorphic Response to Fires, Floods, and Climate Change in Yellowstone National Park; Natural and Anthropogenic Influences on Stream Systems**

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Objectives: The extensive 1988 Greater Yellowstone Area (GYA) fires constitute a landscape disturbance of rare magnitude, and one with important ecological, geomorphic, and climatic implications. In order to provide a longer-term perspective on this event, we propose to investigate the history of Holocene sedimentation in northeastern Yellowstone, using actualistic study of modern fire-related and pre-fire sedimentation as a guide for interpretation of the stratigraphic record. A detailed, highly dateable record of Holocene fire-related sedimentation events is preserved in alluvial and colluvial deposits of the Soda Butte Creek drainage. Comparison of the timing of fire-related events with paleobotanical and climate proxy records can elucidate the relative importance of changing vegetation and hydrological regime, wildfire effects, and intrinsic thresholds in the geomorphic system. Recent changes in stream channels determined through analysis of airphotos, historical photos, and re-surveying will be evaluated in the context of flood history, changes in riparian vegetation, and intrinsic characteristics of basins and channels. We will also examine historical records of meteorological and regional atmospheric conditions associated with both extensive fires and large floods in the GYA, and attempt to develop analogs for climate associated with fire-related sedimentation and other hydrological processes. This research will help to assess the short-term geomorphic response to the 1988 GYA fires, as well as indicate possible consequences of potential global warming and climatic change for stream ecosystems and landscapes in the GYA ecosystem. We are also investigating the effects of a dam-break

flood, which washed acid-generating and metals-rich mine tailings down Soda Butte Creek from the Cooke City area into Yellowstone National Park.

Findings: The geomorphic response to fires component of the project is largely complete and results are detailed in several publications. The flood history component is ongoing; we have identified major floods on the Lamar River system of substantially greater peak discharge than the 1996 and 1997 floods (the largest in gauge records): in 1918, the early 1870s and possibly near 1800. Preliminary results of this work are published in a 1995 *Friends of the Pleistocene Field Guide* available from Meyer. We have also collected a large amount of data on the map distribution, metals concentration, and particle size of floodplain mine tailings deposits along Soda Butte Creek, and have estimated their total volume and mass. Copper and lead concentrations are of particular concern. We have also reconstructed the dam-break flood, a high discharge but short duration event.

Title: **Volcanic and Hydrothermal Studies of Yellowstone National Park: Part 1: Anisotrophic Magnetic Susceptibility of Ignimbrites of the Yellowstone Plateau Volcanic Field. Part 2: Magnetic Susceptibility and Remanence Measurements of Selected Rocks. Part 3: Assessment of Hydrothermal Explosion Deposits in Yellowstone National Park. Part 4: Geochemical Studies of Thermal Fluids in YNP.**

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Additional Investigators: Dr Robert L. Christiansen, Dr. Wayne C. Shanks

Objectives: 1.) To assess the validity of using anisotropic magnetic susceptibility as a flow direction indicator in ignimbrites focusing on the Lava Creek Tuff with less emphasis on other volcanic units in the Yellowstone Plateau volcanic field. I plan to examine the ignimbrites in various conditions including a wide of degree of alteration states, proximity to the Yellowstone Caldera, influence of pre-existing topography, stratigraphic positions within a particular exposure, etc.. Measurements will be compared with field data. 2.) To estimate locations of the individual volcanic vents and assess the structure of Yellowstone caldera in relation to caldera forming processes. 3.) To collect oriented core samples and hand samples of various lithologies, primarily volcanic in composition, for magnetic susceptibility and remanence measurements. These measurements will be used in evaluating results from detailed aeromagnetic surveys currently being conducted. The oriented core samples will be collected using a

gasoline-powered drill: cores are 1" in diameter and 3-4" long; about 10-12 samples distributed over 6-12 meters distance are collected for each site. Care will be taken to fill the core holes. 4.) To examine the character, extent, age, composition, and triggering mechanisms of hydrothermal explosion deposits identified in Yellowstone National Park, with emphasis on those north of Yellowstone Lake.

Findings: 1.) Multiple sites in the Lava Creek Tuff were collected and analyzed to test the technique using anisotropy of magnetic susceptibility as a flow direction indicator suggest this is a promising tool and yield consistent results. We will continue to collect and analyze more samples in FY99. We are also studying the effects of hydrothermal alteration on magetic susceptibility for the Lava Creek Tuff and will be analyzing our samples for alteration minerology and stable isotopic data. 2.) In FY98, we began our hydrothermal explosion breccia study. We currently have samples submitted for radiocarbon analyses, stable isotopes, alteration mineralogy, and fluid inclusion analyses. We plan on continuing our fieldwork and analyses in FY99. 3.) Studies on the magnetic properties of volcanic and sedimentary rocks in conjunction with our analysis and interpretation of the high resolution aeromagnetic survey of YNP are ongoing and will continue in FY99. A manuscript on this data and interpretation is in progress. 4.) Stable isotopes and geochemistry of stream, lake, and thermal waters are being used to understand the origin of geothermal systems. In FY99, field and laboratory work will continue.

Title: **Sulfur Speciation and Redox Processes in Mineral Springs and their Drainages**.

Principal Investigator: Dr. Kirk Nordstrom
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Additional Investigators: Dr. Martin Schoonen, Dr. Gordon Southam

Objectives: The primary objectives are to determine the actual speciation of dissolved sulfur species as they undergo oxidation and volatile losses for H_2S, and to study the evolution of acidic drainages unaffected by pyrite oxidation. Intermediate sulfoxy anions, such as thiosulfate, have been implicated as complexing agents to solubilize and mobilize metals in the formation of ore deposits and as monitors of volcanic activity. We hope to relate sulfur speciation in hot springs and their overflow drainages to rates of oxygen diffusion and solubility. We also hope to learn how the chemistry of acidic drainages dominated by elemental sulfur oxidation differs from those dominated by pyrite oxidation.

Findings: Two USGS Open-File Reports containing analyses of 99 hot spring, geyser, and surface water samples from 1974-75 sampling, and 42 samples from 1994-95 sampling, have been published and are available for free from the senior investigator. A proceedings paper summarizing the occurrence and

interpretation of thiosulfate in Yellowstone waters has also been published.

During the 1997 field season, eleven water samples were collected from springs in Norris Geyser Basin and from Brimstone Basin, southeast of Yellowstone Lake. During the 1998 field season, twenty-two water samples were collected from Norris Geyser Basin, Gibbon Geyser Basin, Heart Lake Fissure Group, and Brimstone Basin. Sampling and onsite analysis was made possible with a mobile laboratory equipped with an ion chromatograph, a portable UV-visible spectrophotometer, a diode-array spectrophotometer, and an autotitrator. In 1997, little or no thiosulfate was found at most locations. Thiosulfate concentrations were significantly high at Cinder Pool and Cistern at Norris. A detailed geochemical interpretation of the sulfur redox chemistry at Cinder Pool, and a survey of H_2S, S_2O_3, and SO_4 in hot spring waters is part of a Ph.D. thesis by Yong Xu (SUNY-Stony Brook), submitted for publication in 1997. Both water sampling (for major and trace elements) and microbial sampling were completed for seven sites along Alluvium Creek and at Brimstone Basin in 1997. Unusual aquatic larval and microbial communities and extremely acidic waters (pH 1.8-3.0) from elemental sulfur oxidation were found. Detailed geochemical interpretations of the sulfur redox chemistry at Cinder Pool and a survey of H_2S, S_2O_3, and SO_4 in hot spring waters in the park are scheduled for publication early this year.

Title: **Impact of Fires of 1988**

Principal Investigator: Dr. Daniel Norton
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Objectives: Assess the impact of the Yellowstone fire ash upon the groundwater geochemistry. Continue the collection, processing, and chemical analysis of ash, soil, and plant material from selected sites within the park. Collect fire-related samples from 15 selected burn areas of both ash and soil to determine annual change in physical and chemical properties, and to document with photographs.

Findings: During the September 1997 field operation in Yellowstone, several sites were observed, photographed, and sampled. These were the sites at Old Faithful and Lewis River. It was determined that the ash layer was maintained much like previous years and the slow growth of Lodgepole Pine was again observed. Samples of ash and soil were analyzed in the laboratory and sieved as in the previously reported procedure. Samples are available for water extraction and chemical determinations as previously accomplished.

Selected sites were sampled in September 1998 at different types of elevation and terrain.

Title: **Quaternary Geology, Geoarcheology, Neotectonics, and Hazards Studies of the Greater Yellowstone Area**

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Additional Investigators: Ken Cannon, Lisa Morgan

Objectives: 1.) Investigate Yellowstone Lake and River level changes associated with caldera inflation/subsidence cycles. 2.) Geoarcheology of sites, particularly around Yellowstone Lake. 3.) Hazards appraisal, particularly late Quaternary faulting, hydrothermal explosion, volcanism, and landsliding. 4.) Outreach, including books, training videos, and high quality videos on Yellowstone geology.

Findings: We documented in more detail changes in Yellowstone Lake level. With Ken Cannon, we found a similar geologic expression for the south shore of Yellowstone Lake.

Title: **Trace Element Partitioning Coefficients for Feldspar in High-Silica Rhyolite**

Principal Investigator: Minghua Ren
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Additional Investigators: Dr. Don F. Parker, Mr. John White

Objectives: On August 13-14, 1998, we collected six samples of rhyodacite from Yellowstone National Park. These samples have been added to our data set of approximately 55 samples of rhyolite. We hope to use these samples to better constrain the values of partition coefficients between feldspar and liquid during rhyolite petrogenesis.

Findings: We analyzed the Yellowstone samples for major and trace element chemistry during winter-spring of 1998-1999. We are currently preparing mineral separates in order to analyze them, so we may

calculate partition coefficients for feldspar. The six Yellowstone samples will be housed in the Baylor Geology department.

Title:	**Analysis of Geyser Periocitiy**
Principal Investigator:	Dr. Stuart Rojstaczer
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Additional Investigators:	Steven Ingebritsen, Paul Silver, Nicholas Bacher

Objectives: Examine variations and geyser periodicity and their controls.

Findings: Geyser periodicity network has been installed. Examination of existing data indicate a small non-linear component in some of the geysers. Some of the geysers respond to both seismicity and variations in atmospheric pressure.

Title:	**Yellowstone Paleontological Survey**
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Additional Investigators:	William P. Wall

Objectives: Provide comprehensive baseline paleontological resource data to park management in a publication format that is presented in a park management perspective. The report will provide recommendations relative to interpretation, protection, resource management, curation, etc. of the park's paleontological resources. The report will generate a paleospecies list, bibliography, updated RMP project statements, and other paleontological resource data for Yellowstone National Park.

Findings: During the 1997 field season, field crews inventoried six new paleontological localities in

Yellowstone. A rare cochliodont crushing tooth from the Mississippian Madison Limestone was discovered and collected. GPS data was collected from the standing petrified trees along Specimen Ridge. Surface exposures of fossilized bone from the Late Cretaceous plesiosaur were collected. The Yellowstone Paleontological Survey Report was completed during late 1997, and will be published by March 1998.

As of 1998, over twenty fossiliferous stratigraphic units have been documented in Yellowstone containing fossil plants, invertebrates, vertebrates, and trace fossils. Yellowstone preserves an extensive geologic record ranging from the Precambrian through the Holocene. Except for the Silurian, rocks of nearly every geologic time period are exposed within the boundaries of the park.

Title: **Operation and Development of an Earthquake and Volcano Information System at Yellowstone National Park**

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Additional Investigators: Sue Nava, Charles Meertens

Objectives: The primary objectives of the Yellowstone seismic and GPS networks are to monitor and assess seismicity and ground deformation that may be related to both volcanic and tectonic earthquake activity. The project tasks include maintenance, recording, routine analyses, and station installation of the Yellowstone Seismograph and GPS Networks (YSN). Data from the YSN provide information for public safety, park and surrounding community management and planning, public information and interpretation, and for scientific research interests. The YSN is designed to monitor earthquakes of the entire Yellowstone volcanic system, including Yellowstone National Park (YNP) and the nearby Hebgen Lake fault zone. The GPS stations provide continuous monitoring of the crustal deformation of the volcanically active Yellowstone caldera. This monitoring system provides real-time earthquake surveillance by a recently upgraded 22-station, 32-component, seismic network telemetered via FAA microwave links (at no cost to the project) to Salt Lake City, Utah, and digitally recorded at the University of Utah Seismograph Stations. Continuous GPS data are recorded at two sites and are archived at UNAVCO (accessible via the Internet). The USGS Volcano Hazards Program jointly funds this cooperative project with partial support form the National Park Service (NPS) for field work. The primary products for this USGS support are annual earthquake catalogs, the services of a regional earthquake and GPS recording and information center, including timely release of unusual earthquake activity reports to the USGS and the NPS.

Findings: In addition to routine network operations, notable efforts under this cooperative agreement during the report period related to: 1.) Continued upgrading and maintenance of seismograph stations against the harsh winter conditions of Yellowstone. This included, (a) continued installation of audio bandpass filters at relay sites in order to reduce interference; (b) replacement of several aging radio transmitters and receivers throughout the network; and (c) VCO system repairs and upgrades. GPS quality station locations continue to be determined using Trimble SSI dual-frequency receivers. Seventy-seven percent (17/22) of the stations of the Yellowstone seismograph network were visited for maintenance during the report period. 2.) Installation of a three component, broadband, digitally-telemetered seismograph station on the northwest side of the Yellowstone caldera at Madison River. Field installation was completed during the report period, but a labor strike by U.S. West and miscellaneous technical problems with the installation of a telephone link between the Salt Lake City airport and the central recording lab prevented completion of the project during this report period. 3.) Installation of three reconditioned L4 seismometers (Norris Junction, Gravel Pit, and Pelican Cone). Continued upgrade of the central receive sites for all stations in the Yellowstone network (Mt. Washburn, Wyoming, and Sawtelle Peak, Idaho). 4.) Assistance to the USGS-NEIC for maintenance of a cooperative U.S. National Seismograph Station (USNSN) located near Yellowstone Lake. 5.) Installation of a continuously recorded GPS receiver at Mammoth to complement a receiver located at Lake. These stations monitor the deformation of the YNP caldera. Data are automatically retrieved via a dial-up telephone line every 24 hours and then incorporated into the UNAVCO GPS archives. 6.) Maintenance of a continuous recording, high-precision GPS station at the U.S. National Seismograph Station with telemetry provided by the USGS VSAT satellite system. Note that the GPS equipment was provided by the NSF cooperative University ARI funds. Installation costs were supported by NSF funds. 7.) Systematic determination of local magnitudes (M L) and M L station corrections using local USNSN, Montana Wood-Anderson station BUT (Butte, Montana), and Utah broadband stations, for all coda magnitude (M C) 3.0 and greater earthquakes located in the Yellowstone region since January 1, 1994. Analysis continued on the recalibration of the Yellowstone coda magnitude scale. Over 100 Wood-Anderson seismograph records principally from BUT and IRCI (Idaho Falls, Idaho) with supplemental data from USNSN stations at Dugway and Yellowstone Lake were analyzed. 8.) Steps towards submitting 18 years of University of Utah short-period waveform data to the IRIS Data Management Center in SEED format. 9.) Continued software development to integrate new digital data streams with existing analog data streams for routine analysis. 10.) Completion of a network inventory for the CNSS and major progress towards a comprehensive station inventory for the IASPEI handbook. Submission several times per day of earthquake catalog data for the Utah region to the Council of the National Seismic System's composite catalog. 11.) Assistance to the NPS with long-term plans for implementing volcano and earthquake hazard assessment and identifying workforce needs. 12.) Analysis of space-time variations of seismic source mechanisms and related stresses of Yellowstone. Discussions with USGS Menlo Park volcano seismology group regarding implementation of long-period event detection software (within Earthworm), and as part of MS student (G. Waite) thesis research on Yellowstone National Park seismicity.

Title: **Ground Penetrating Radar Studies at Mammoth Hot Springs**

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Additional Investigators: Ms. Laura Joss, Dr. William Sill

Objectives: The purpose of this study was to identify possible geologic risks involved in future construction near Mammoth Hot Springs, Yellowstone National Park. Ground penetrating radar was used to help identify these geologic hazards.

Findings: The Mammoth Hot Springs area features a complex and extensive assemblage of hydrothermal carbonate rocks. Due to the rapid and often haphazard manner in which the associated thermal features emerge and disappear, and because of the highly soluble nature of the rocks themselves, a thorough investigation of the area's subsurface is necessary before large-scale development proceeds. On May 13, 1997, ground penetrating radar (GPR) and spontaneous potential tests were conducted in the Mammoth Hot Springs area. These initial tests were conducted at Opal Terrace, the mail carrier's cabin, and near the icehouse. The results of these initial tests were encouraging, and on June 18, 1997, the Montana Tech of The University of Montana Geophysical and Geological Field Camp collected GPR and vertical electrical sounding (VES) data near the mail carrier's cabin. Moreover, a small test of radar antenna frequencies was conducted near the icehouse at Mammoth Hot Springs on August 4, 1997. GPR was employed to delineate subsurface geometry and detect dissolution features. With a signal penetration depth of over 18 meters and a vertical resolution of 0.4 meters, the GPR survey provided little evidence of large subsurface cavities in the region of the mail carrier's cabin. Those cavities that do exist are either too small or are too deep to be a concern. Possible cavities, however, were detected at Opal Terrace and at the icehouse site. Many anomalies located by the GPR system were interpreted as cultural, or man-made objects. In addition, the presence of small fractures in the area must be considered before any development proceeds. These fractures may be related to historic subsidence. Furthermore, while the area near the mail carrier's cabin currently is geothermally inactive, there is no guarantee that this site will remain inactive in the future. No additional data was collected in 1998. However, three papers for publications were prepared and one of these papers was published in 1998.

Title: **Low 18-Oxygen Rhyolites in YNP: Using Zircons to Establish the Timing and Mechanisms for 18-Oxygen Depletion in Granitic Magmas**

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Additional Investigators: Dr. Ilya Bindeman

Objectives: 1.) To determine magmatic geochemistry of volcanic rocks within the Yellowstone Caldera. 2.) To elucidate the importance of hydrothermal fluids in altering rock compositions. 3.) To determine the causes of low oxygen-18 magmas.

Findings: Samples were collected in July 1996. Samples were prepared in Madison during 1997-98, and isotope analyses were started in 1998. Additional sampling is planned for 1999.

Title: **Eruption History of the Sepulcher Formation as Determined by Geochemistry**

Principal Investigator: Dr. Clyde Webster
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Additional Investigators: Dr. Harold Coffin

Objectives: To use geochemical analyses and statistical methods in the analysis of the breccia and rock and ash samples from Yellowstone Fossil Forest located in the Specimen Creek area in attempts to clarify the origin and history of the breccia flows and the petrified trees that are buried by them.

Findings: During 1997, only two days were spent in the field. The remainder of the research time has been used to complete the laboratory analyses of the samples and the statistical analyses of the data. Statistical analysis is almost complete, however from the data it has become evident that there are at

least two sites within the study area which must be re-sampled. In 1998, two sites were re-sampled for analyses and a GPS Survey of the major fossil trees within the Specimen Creek Area was conducted. The ash samples were submitted for analyses and the data is currently being analyzed. The GPS data will be transferred to an expanded topographic map and submitted later.

Title: **Groundwater-Flow Assessment of the Upper Soda Butte Creek Drainage Basin, Park County, Montana and Wyoming**

Principal Investigator: Dr. Willis Weight
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Additional Investigators: Amy Huskey, Alan English

Objectives: To understand the basic hydrogeology of the Upper Soda Butte Drainage from Silver Gate to Cook City. Characterization will be performed through performing pumping tests, static water-level surveys, and stream gauging. Additional analysis of the role of bedrock is to be explored. The data will be integrated into a groundwater flow model.

Findings: Three aquifer tests were performed and water level surveys were conducted in summer and fall 1997, and throughout the fall of 1998. Stream gauging was performed. A groundwater flow model using a graphical interface, GMS, was used to create a three-layer model of the area. This was put together as part of an MS thesis by Amy Huskey. She defended her thesis, but corrections are still underway. Alan English is continuing a thesis study in the Silver Gate area, including water-quality data.

Title: **Postglacial Fire Frequency and its Relation to Long-Term Vegetational and Climatic Changes in Yellowstone Park**

Principal Investigator: Dr. Cathy Whitlock

See Fire

Title: **Hydrothermally-Affected Soils of Yellowstone National Park**

Principal Investigator: Dr. Michael A. Wilson
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Additional Investigators: Ann W. Rodman, Henry F. Shovic

Objectives: 1.) Document field and laboratory characteristics of selected acid sulfate and neutral chloride soils within Yellowstone National Park. 2.) Determine pedological and landscape genetic processes relative to alteration chemistry in selected hydrothermal areas. 3.) Investigate mineral stability and secondary mineral formation in both neutral chloride and acid sulfate environments.

Findings: Field investigations in 1998 focused on: 1.) Range and variability of soil properties in the Lower Geyser Basin. In part, we are examining vegetational patterns relative to soil characteristics. Soil samples currently being analyzed. 2.) Diurnal and seasonal variability of soil temperature in both acid sulfate and neutral chloride areas. Preliminary data was collected in 1998.

HERPETOLOGY

Title: **1. The Distribution and Status of Amphibians and Reptiles in Yellowstone National Park. 2. Monitoring Amphibian Populations in the Greater Yellowstone Ecosystem. 3. Adaptive Management Component of Amphibian and Reptile Surveys, Monitoring, and Research.**

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Additional Investigators: Debra Patla, Jeremy Hawk, Char Corkran

Objectives: 1.) Determine the distribution of amphibians and reptiles in Yellowstone National Park. 2.) Monitor amphibian populations to determine status and trends. 3.) Contribute to adaptive management by conducting surveys, compiling information, and formulating recommendations for the conservation of amphibian and reptile populations in areas that may be affected by development projects or other human activities. 4.) Test hypotheses concerning the causes of changes in amphibian and reptile populations. The 1997 project investigated relationships among water chemistry, toad breeding, and densities of the bacterium *Aeromonas hydrophila*, the causative agent of redleg disease. The 1998 project investigates fluctuating asymmetry in frog and toad limbs.

Findings: 1.) Distribution. We have continued to increase the amount of distribution information for amphibians and reptiles in Yellowstone National Park. Employing experienced volunteers, we conducted surveys in three backcountry areas in 1997: Gallatin River drainage (Daly, Black Butte, and Specimen Creeks), the upper Yellowstone River (Yellowstone Lake to Thorofare Creek), and Bechler Meadows. This was a pilot effort for mapping distribution in remote areas. In 1998, surveys were conducted in the Pebble, Fan, and Canyon Creek drainages, Delusion Lake, & the Promontory. Observations are entered into a GYE database and used to generate maps.

2.) Monitoring. We continued monitoring at six amphibian breeding sites in Yellowstone. Results of our six years of monitoring at these sites are being compiled for a report and publication. We are expanding our monitoring program to include a network of sites across the Greater Yellowstone Ecosystem, with funding from the National Fish and Wildlife Foundation. In 1997, we designed and tested a system for randomly selecting potential monitoring areas. In the future, we plan to apply this

system for increasing the number of monitoring sites and the effectiveness of monitoring in Yellowstone National Park. The expanded monitoring program will enable us to detect declines in amphibian populations across the Greater Yellowstone Ecosystem.

3.) Adaptive management. Amphibian breeding sites and other important habitat exist in some areas adjacent to park highways. These may be vulnerable to road reconstruction and expansion projects. Other park projects and activities may also affect local populations. Since 1993, we have written a series of reports to identify important sites and provide recommendations for protecting habitat and mitigating potential impacts. In 1997, we completed a report for the Mammoth-Norris section of highway, identifying 19 occupied sites that appear to be at risk from road expansion and four sites that warrant high priority status for protection. We also evaluated an area near Canyon Village where facilities are planned for expansion, and completed a report, identifying three occupied sites. We continued area surveys in the summer of 1997 and updated the report in January 1998. In 1998, we surveyed areas where introduced trout may be removed with piscicides in order to restore native fish and submitted a report on amphibian habitat use and conservation. We also surveyed in the Old Faithful area where sewage treatment facilities will be reconstructed. Data from all previous road survey projects were compiled in a GIS (ArcView) project.

The spotted frog (*Rana luteiventris*) population near Lake Lodge has declined about 75% since the 1950s, according to research we conducted from 1993-1995. To avoid the trampling of metamorphosing frogs by pastured horses at one of the breeding pools in the area, we recommended and participated in the construction of a log-and-cable fence around the pool. We will continue to monitor the site. Data from all previous road survey projects are being compiled in a GIS (ArcView) project. This project will allow park managers to quickly identify the location of important and vulnerable sites. The ArcView project will be completed by May 1998.

4. Research. Boreal toad (*Bufo boreas boreas*) populations have declined and disappeared throughout much of the Greater Yellowstone Ecosystem over the past 40 years, but populations have persisted in many geothermally influenced wetlands. At many sites where toads continue to breed, there is unusual water chemistry, including high conductivity and high acid neutralizing capacity. We hypothesized that toads may be protected from a common bacterial disease, known as redleg, by the unusual water chemistry found at these sites. In 1997, we sampled 28 sites. Contrary to expectations, we found that bacterial densities increased with conductivity, and that the occurrence of toad breeding was positively related to bacterial densities. We are preparing a report of this study for the University of Wyoming National Park Service Research Center. In 1998, we will continue the laboratory portion of this study, testing for relationships among water chemistry, water temperature, bacterial densities, and boreal toad tadpole resistance to redleg disease.

In 1998, we tested whether fluctuating asymmetry (FA) exists in frog and toad populations at three locations in YNP. FA may indicate stress and thus be used as a monitoring tool.

HISTORY

Title: **Historical Survey and Evaluation of Concession and Administrative Buildings in Yellowstone National Park**

Principal Investigator: Ms. Janene Caywood
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Objectives: To conduct an inventory of all historic buildings in Yellowstone National Park. Each building will be documented through a written architectural description, and with black and white photographs. Historic Resource inventory forms will summarize information for each building. HRA is also preparing maps to accompany the nominations. DOEs are to be prepared by Mary Culpin as part of the multiple property submission for YNP. HRA's principal deliverables will be sets of historical resources notebooks for the park, the Intermountain Regional Office of the park service, and the Montana and Wyoming State Historic Preservation Offices.

Findings: The current estimated completion date for this project is the end of July 1999.

Title: **Viewfinders: Photography and Geography in the National Parks**

Principal Investigator: Dr. Emily Greenwald
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Objectives: The project uses library, archival, and museum collections to trace the role photographs and photography have had on park design. The larger project takes examples from many parks, including Yellowstone, Yosemite, Arches, Grand Canyon, and Acadia.

Findings: Research has been conducted at Yellowstone, Yosemite, and Arches National Parks. Work will resume during the summer of 1999.

MAMMALOGY

Title: **Bat Roosts in Historic Park Structures in the Rocky Mountain Region**

Principal Investigator: Dr. Michael Bogan
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Additional Investigators: Mr. Keith Geluso

Objectives: To determine temperature regimes in sites occupied and unoccupied by bats; assess the magnitude of existing conflicts between roosting bats and historic structures; initiate inventories for bats in and near developed areas of parks where likelihood of conflict is greatest; and provide outreach and consultation to other parks with similar problems.

Findings: A written report was submitted to all park cooperators on March 19, 1998, and a conference call was held thereafter to update cooperators in NPS on 1997 results and plans for 1998. As per the study plan for this work, activities continued in 1998, and a full written report will be submitted in 1999.

Title: **The Bats of Yellowstone Park and Vicinity**

Principal Investigator: Mr. Thomas Butts
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Additional Investigators: Don Nelson

Objectives: Public education.

Findings: Four bats were captured at the Buffalo Ranch on the evening of July 2, 1996. All were adult

female little brown bats (*Myotis lucifugus*). All were gravid. Weights ranged from 6.1 to 7.0 grams, forearm length ranged from 37.8 to 38.6 mm. All bats were released after capture.

Title: **Effects of 1988 Fires on Ecology of Coyotes in Yellowstone National Park: Baseline Succeeding Wolf Recovery.**

Principal Investigator: Dr. Robert Crabtree
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Additional Investigators: J. Sheldon, D. Smith, C. Wilmers, D. Bopp, P. Moorcroft

Objectives: Document long-term effects of the 1988 fires on the population dynamics and behavioral ecology of coyotes. Document the impacts of wolf restoration on coyote population and behavioral ecology including effects of coyote prey and competitor species. Continue long-term monitoring of coyote populations by adherence to those objectives listed in previous reports and peer-reviewed publications.

Findings: Project is ongoing and is in Phase II: wolf colonization. A variety of significant behavioral and demographic effects of wolves on coyotes have occurred since the release of wolves in 1995. The direct effects of fires on coyotes continue to be insignificant, however, indirect effects on the small-mammal prey base community continue. A functional increase in coyote (and other scavengers: eagles, ravens, bears) has occurred in response to the availability of wolf carcasses.

Title: **Elk-Snow Project**

Additional Investigators: P. Moorcroft, Kirk Johnson, Phil Farnes, Mark Lewis

Objectives: 1.) How does snow affect the distribution of elk during winter on Yellowstone's Northern Range? 2.) What other factors, such as winter temperature, forage, and predator/prey density, are affecting their distribution?

Findings: Analysis and writing are currently underway. Preliminary findings indicate that snow characteristics and habitat affect the distribution and foraging behavior of elk during winter. Lora Ballinger, a graduate student at University of Utah, has just completed her M.S. thesis. Her work involved the development and testing of an empirically based dynamic model that predicts elk movements on the northern range. No fieldwork was conducted in 1998.

Title: **Small Mammal Communities: Prey-Base for Carnivores**

Additional Investigators: D. Despain, K. Wilson, and K. Johnson

Objectives: 1.) Develop an inventory and monitoring method for small mammals (carnivore prey base) on Yellowstone's northern range. 2.) Describe and quantify the effects of the 1988 fires on the small mammal community. 3.) Quantify habitat use of the major small mammal prey. 4.) Estimate abundance of major small mammal prey on the northern range according to major habitat types. 5.) Collaborate with cooperating parties. 6.) Continue long-term monitoring of small mammal populations, especially the major prey species.

Findings: A final report and book chapter have been completed. Various scientific publications are now being prepared. Significant effects of the 1988 fires have been documented. Dr. Kenneth Wilson of Colorado State University is currently working with the principal investigator to write three manuscripts for submission to scientific journals. Fieldwork was conducted in July and August to monitor small mammal populations in the Lamar Valley area.

Title: **Physiological Stress Responses, Aggression and Social Dominance in Group Living Species**

Principal Investigator: Dr. Scott Creel
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Additional Investigators: Jennifer Sands, Marion Riviere

Objectives: To determine relationships between stress hormone levels (glucocorticoids), reproductive hormone levels (estradiol, progesterone, testosterone), aggression, and social dominance in free living wolves.

Findings: Fecal hormone sampling and behavioral observations are underway. 138 fecal samples have been collected as of this report. Of these, 10 are from known individuals. Behavioral observations and fecal sampling will be increased this year, with the arrival of a graduate student, Jennifer Sands, who will begin full time field work in January.

Title: **Grizzly Bear Behavior, Genetics, and Ecology**

Principal Investigator: Dr. Steven French
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Jackson, WY 83001

Additional Investigators: Marilyn G. French

Objectives: 1.) Long-term study of grizzly bear behavior in the Yellowstone ecosystem. 2.) Development of nuclear DNA microsatellites for Yellowstone grizzly bears to be applied to genetic diversity and demographic monitoring programs.

Findings: Bear behavior identified previously included the confirmation that a significant portion (perhaps 1/3 to 1/2) of the Yellowstone grizzly bear population spends up to two months each year feeding almost exclusively on army cutworm moths in the alpine regions of the Yellowstone ecosystem. Army cutworm moths are the highest concentration of any natural food for grizzly bears in the Yellowstone ecosystem, greater than pine nuts, cutthroat trout, and ungulates.

Based upon the geomorphological characteristics at known moth aggregation sites, we have developed a predictive model to identify other potential areas within the Yellowstone ecosystem. In 1990 and 1991, we tested this model by making surveys at four areas previously unknown to have moth aggregation areas. All four contained army cutworm moths and three had evidence of bear feeding activity.

In developing the protocol for the new genetic study, we originally intended to develop a set of 30 microsatellites by isolating tetrameric repeats from the grizzly bear genome. This decision was based upon the human data which indicated that while tetrameric repeats are less abundant and less apt to be polymorphic than dimeric repeats, they are also less prone to yielding ambiguous results, caused by "stutter" bands in the gel due to PCR artifacts. Given the need for unambiguous discrimination between genotypes, and the practical advantages of having a "fool-proof" laboratory protocol, this seemed to be a good trade off – more work to develop tetrameric loci, but considerable gains in efficiency and accuracy in routine applications.

Unfortunately, while the theory was sound, this strategy turned out to be unworkable in practice, since grizzly bear genome appears to be depauperate in informative tetrameric loci. After a significant amount of research, including the development of an enriched library, screening 570 clones, and sequencing 54 strongly hybridizing clones, we found only 11 potentially informative loci, of which only three were immediately usable (YGF-TETRA c series). While of considerable evolutionary interest (e.g., the grizzly bear genome appears to be different from other carnivores, such as the canids, which contain reasonably informative tetrameric loci), these results essentially eliminated this strategy from further consideration.

Accordingly, we turned our focus to dinucleotide microsatellite loci, and used our basic enrichment strategy to search for genomic segments carrying (AC)n and (AG)n dimeric repeats. Of these two motifs, the (AC)n microsatellites were by far the most informative, and the bulk of our subsequent efforts directed to the class. After enrichment, a set of 1,920 clones were screened and the 618 clones with strong hybridization signals were analyzed further. One hundred and fifty of these clones were sequenced, resulting in the definition of a set of 66 microsatellite loci (YGF-AC c series). The degree of polymerism of these loci was evaluated by testing them against a panel of 16 grizzly bears, of which six were from the Yellowstone ecosystem, and the rest from various localities in Canada and Alaska, including Kodiak Island. This indicated that 37 were clearly polymorphic, though nine of these will require considerable PCR optimization before reliable genotypes can be obtained. We also detected a sex-specific locus, which will be useful for sex determination studies. Of the remaining 28 loci, nine have some potential, and the final 17 are probably not worth expending more resources on at this time.

Since the YGF-AC c series contains a total of 28 already usable polymorphic microsatellite loci, we decided to increase the efficiency with which these loci could be employed by developing a "multiplexed" set. These loci are distributed into three mulitplexed sets and the PCR protocols were optimized. Therefore, the full set of 28 YGF-AC c genotypes can efficiently be defined by only three gel lanes. Hence, 10-12 individual samples can be fully genotyped in a single ABI run, and more than 30 individuals per run with the new high resolution models.

While not as informative as the (AC)n dimeric repeats, the (AG)n repeats also resulted in some informative polymorphic loci. Here we only screened 570 clones and found 68 highly positive clones. Ultimately we characterized 90 (AG)n loci (YGF-AG c series). After screening the panel of 16 grizzly bears, only 11 were potentially informative, and of these, only seven could be used immediately. Further work will likely result in finding more polymorphic (AG)n loci.

In summary, we now have a total of 38 polymorphic grizzly bear microsatellite loci that are immediately usable, including 28 of the YGF-AC c series, 7 of the YGF-AG c series, and 3 of the YGF-TETRA c series. We will begin to apply these loci to define the genetic profiles within the Yellowstone grizzly bear sample set from known individuals. In addition, we will compare these results to what would have been achieved if we had only used the seven or eight black bear loci. As soon as this paper is completed and submitted for publication (about the first part of 1999), we will make these loci available to the scientific community for immediate use in other grizzly bear genetics studies.

Title: **Development of Aerial Survey Methodology for Bison Population Estimation in Yellowstone National Park**

Principal Investigator: Dr. Robert Garrott
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Additional Investigators: Steven C. Hess, L. Lee Eberhardt

Objectives: The overall objective of this study is the development of aerial survey methodologies for statistically rigorous estimation of the bison population in the Yellowstone area that will strive for a 95% confidence interval target precision level of ± 20% of the point estimate. These methodologies will allow NPS resource managers to conduct aerial surveys that provide scientifically defensible population estimates to address ecological conditions and epidemiological management issues of Yellowstone bison.

Findings: The survey methodology we are developing quantifies a sampling universe and sampling units with a computer geographic information system, standardizes search effort, employs a stratified sampling design which accounts for undetected animals, and uses an aircraft global positioning system to record data locations. We spent 19.1 hours in four flights surveying bison during winter, not including ferry time. The fewest bison we detected during a complete winter survey was 1,814, and the highest number of bison we detected was 1,899. Concurrent intensive ground surveys, or 'double sampling', in the Madison-Gibbon-Firehole (MGF) areas in winter were used to estimate the magnitude and variability in detectability during specific aerial surveys. In comparing these simultaneous ground and aerial surveys primarily in winter, only 77% of the groups were detected from aircraft, although 93% of individual bison were detected. We spent 37.3 hours in 13 flights surveying bison in spring and summer. The fewest bison we detected during a complete spring or summer survey was 1,921 and the highest number of bison we detected was 2,102. Social behavior shows that in summer, as much as 70% of the entire bison population is aggregated in large groups and highly visible in Hayden Valley during breeding. Conducting surveys during this time may provide for both higher detectability and smaller spatial extent than in winter, when bison occupy a larger area and occur in smaller groups. Detectability was relatively high in comparison to aerial surveys of other species, although many small groups and solitary bison were not detected from aircraft, which biases population estimates downward. Low variability between counts and high detectability suggest that precise and unbiased population estimates should be readily obtainable.

During the current 1998-99 winter field season, we attempted to conduct simultaneous winter season ground and aerial surveys in the Madison-Gibbon-Firehole areas since mid-December. However, weather has made it difficult to conduct flights. We plan to conduct approximately six to eight surveys

during the next three winter months of the 1999 season with simultaneous ground surveys in both the MGF and in the northern range of Yellowstone to determine detectability in these two major areas of winter bison occupation.

Title: **Ecological Status of Mule Deer of the Northern Yellowstone Winter Range**

Principal Investigator: Dr. Peter Gogan
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Additional Investigators: Edward Olexa, Tom Lemke

Objectives: 1.) Determine the summer ranges of deer utilizing the northern winter range. 2.) Determine use patterns of deer on the northern winter range. 3.) Determine annual reproductive performance and fawn survival. 4.) Determine numbers and age and sex structure of the wintering herd.

Findings: This study has been conducted under the auspices of the Northern Yellowstone Cooperative Wildlife Working Group. Sixty adult doe mule deer were net-gunned and radio-collared on the northern range in March 1993. An additional 25 adult does were captured and radio-collared in March 1995. Animals were located from a fixed-wing aircraft at approximately 10-day intervals between April 1993 and May 1997. Locations were determined with a GPS unit in the aircraft. Age and sex composition counts were completed in early winter, and total counts and adult/fawn ratios were completed in May of each year.

Radio-tracking data reveal that mule deer wintering in the Gardner Basin on the east side of the Yellowstone River summer to the east of the winter range with one exception. Some deer wintering in the Slip N Slide drainage moved to the west to the vicinity of Big Sky, Montana. Similarly, deer wintering on the west side of the Yellowstone River summer to the southwest of the winter range.

Data on the age and sex composition for the period of study have been combined with previously published information to track population trends. Analysis reveals that fawn survival is closely linked to an index of winter severity, particularly to snow water equivalency.

Title: **Seasonal Movements and Habitat Selection by Bison in Yellowstone National Park**

Additional Investigators: Edward M. Olexa, John Mack

Objectives:To determine movement patterns of YNP bison and relate these movements to range conditions such as herbaceous standing crop, growth stage, snow depth, and snow water equivalency in the areas vacated and occupied by bison.

Findings: Forty-five bison were net-gunned and radio-collared in October 1997. An additional 40 bison were radio-collared as part of on-going epidemiological studies of bison and brucellosis. Five bull bison were net-gunned and radio-collared on the northern range in March 1998. Aerial radio-tracking flights for all instrumented bison have been on going since that time. Bison are being relocated at approximately 10-day intervals. Locations are being determined with a differentially correcting GPS unit in the aircraft.

Title: **Some Population Characteristics of the Yellowstone National Park Bison Herd, 1996-2001**

Additional Investigators: Wendy E. Clark, Edward M. Olexa, John Mack

Objectives: To determine basic population parameters of Yellowstone National Park bison

Findings: Samples were secured opportunistically from bison slaughtered beyond the boundaries of YNP during the winter of 1996-97. We found marked differences in the age structure of bison killed in the vicinity of West Yellowstone and Gardiner. This difference is likely attributable to largely non-selective removals at West Yellowstone and selective removals at Gardiner. Pregnancy rates increased continuously between one and six years of age. Cross-referencing of our age data with Montana Department of Livestock seroprevalence data revealed a general upward trend in seroprevalence with age for female bison. Our sample of male bison was too limited for this comparison.

Title: **Monitoring the Response of Small Mammal Communities to Climatic Change Using Raptor Ecology**

Principal Investigator: Dr. Elizabeth Hadly
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Additional Investigators: April C. Craighead

Objectives: The objective of this study is to identify nesting and roosting areas for three species of raptors: common raven, great horned owl, and red-tailed hawk, and collect pellets from these birds and analyze their prey items.

Findings: During 1998, I collected 530 pellets from 18 pairs of raptors throughout Yellowstone National Park. Preliminary results of the owl pellets show a high diversity of prey species, including amphibians, bats, birds, fish, and mammals.

Title: **Bat Survey along the Mammoth to Norris Road Corridor**

Principal Investigator: Mr. Paul Hendricks
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Additional Investigators: Sam Martinez

Objectives: This study was conducted as part of a resource inventory along the Mammoth to Norris road corridor to assess potential impacts on bats related to proposed highway construction. Identification and distribution of bats species along this corridor were assessed through use of mist nets and ultrasound bat detectors, and inspection of caves in the Mammoth area.

Findings: A total of 33 sites were studied, including a known maternity pit cave, cold subalpine ponds and other wetlands, bridges, and streams. Bats were detected at 19 (55.9%) of 33 sites. Wet and cold weather at the time of the surveys made mist net activity ineffective. Townsend's big-eared bats were present in Devil's Kitchen pit cave, and detected at one additional site. Big brown bat was detected at nine sites, silver-haired bat at six sites, hoary bat at two sites, long-eared Myotis (*Myotis evotis*) at one site, fringed Myotis (*M. thysanodes*) at one site, and unidentified Myotis at 13 sites. All survey work was

conducted in August and September. Surveys in mid-summer under better weather conditions are likely to determine the presence of bats at many additional sites.

Title: **Cougar-Wolf Interactions in Yellowstone National Park: Competition, Demographics, and Spatial Relationships**

Principal Investigator: Dr. Maurice Hornocker
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Additional Investigators: Toni K. Ruth, Dr. Howard Quigley

Objectives: 1.) Document interspecific killing and the characteristics of the cougar population, including population size, survival, cause-specific mortality, and natality, and compare with analogous estimates made prior to wolf restoration (Phase I data; Murphy 1998). 2.) Assess competition, habitat, and food use characteristics of the two species. 3.) Quantify spatial interactions between cougars and wolves. 4.) Assess the effects of cougars on elk and mule deer populations as influenced by the presence of wolves. 5.) Communicate research findings to state and federal agencies and the general public through annual technical reports, research updates, and presentations.

Findings: The Yellowstone Cougar Phase II project was approved and permits were issued on March 10, 1998. A two-week capture effort (March 13-27) resulted in the capture and radio collaring of one adult female cougar and one female kitten. The adult female cougar's range overlaps with the home range area of the Rose Creek wolf pack. Winter capture work resumed in mid-December 1998, and will continue through late March 1999. Capture of cougars and ground track transects will be conducted to estimate the cougar population on the northern range. Radio-telemetry monitoring of radio-collared individuals will be used to quantify cougar survival, cause specific mortality, and natality of the cougar population (Objective 1).

Twenty-eight cougar kills have been located since the initiation of the study. Elk and mule deer comprise the majority of the kills thus far (Objective 5).

Aerial and ground telemetry monitoring of cougars and wolves were coordinated with wolf coordinator, Dr. Doug Smith, and wolf biologist, Dr. Kerry Murphy, YNP. Four established wolf packs (Leopold, Rose, Druid, and Chief Joseph I) currently overlap the primary cougar range in the northern Yellowstone ecosystem.

Winter 1999 field activities will involve intensive capture work and continued daily ground and weekly aerial telemetry monitoring of both cougars and wolves as coordinated with wolf project personnel. Predation sequences (following methodology of Murphy 1998) will be conducted on radio-collared cougars by searching consecutive radio-location sites for periods of 10 to 60 days until three to four large prey kills are documented. Other cougar kills will be documented opportunistically and scats collected for food habits information.

Title: **Impact of Wolf Reintroductions on the Foraging Efficiency of Elk**

Principal Investigator: Dr. John Laundre
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Pocatello, ID 83209

Additional Investigators: Dr. Lucina Hernandez

Objectives: Determine what impacts the reintroduction of wolves might have on the foraging efficiency and thus, the survival of elk and bison in Yellowstone National Park.

Findings: During 1997, 118 feeding bouts by elk were observed. Of these, 65 were in the area where wolves currently occur, and 53 in areas where wolves have yet to establish. In the area with wolves, five bouts were of males, 27 of females with calves, and 33 of females without calves. In the area without wolves, 13 were of males, 15 of females with calves, and 25 of females without calves. During 1998, 120 feeding bouts by elk were observed. Of these, 60 were in the area where wolves currently occur and 60 in areas where wolves have yet to establish. In the area with wolves, 20 bouts were of males, 20 of females with calves, and 20 of females without calves. In the area without wolves, 20 were of males, 20 of females with calves, and 20 of females without calves.

Results of analysis for 1996 indicated that females with calves and females without calves foraged significantly less and surveyed significantly more in the area where wolves were. There was no difference for males. Data from 1997 indicated the same significant differences for females. Additionally, both female groups foraged significantly less and surveyed significantly more in areas with wolves in 1997 over their 1996 rates. Additionally, females with calves spend even less time feeding and more time observing than females without calves. Preliminary analysis of data from 1998 indicate a similar pattern as found for 1997. This suggests that elk in wolf areas stabilized their level of vigilance.

Data were also collected on the vigilance of bison in wolf and non-wolf areas. Preliminary results of

those data indicate that bison, too, are responding to the presence of wolves with a similar pattern: no response by males, an intermediate response by females without calves, and the greatest response by females with calves.

Data were also collected on the distribution of pellet groups (elk) and fecal piles (bison) relative to the distance from forest edges. Preliminary analyses for areas with wolves indicate that significantly fewer elk pellet groups were found in open areas greater than 300m from forest edges. This pattern was not found in non-wolf areas.

Research efforts this year will be to determine if the patterns are consistent over another year, and will include observations on bison. I will also collect more data on the distribution of elk and bison relative to forest edge in wolf and non-wolf areas.

Title: **Small Mammal Biodiversity in Selected Habitats Between Tower and Canyon, and at the Hoodoos.**

Principal Investigator: Dr. C. Allan Miller
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California, PA 15419

Objectives: To obtain baseline information on species composition of small mammals and their population densities at the Hoodoos and to survey small mammal diversity at 11 selected sites from Tower to Canyon.

Findings: Twelve sites were studied. Species present include *Clethrionomys gapperi*, *Tamias amoenus*, *Tamias umbrinus*, *Spermophilus lateralis*, *Peromyscus maniculatus*, *Ochotona princeps, Microtus montanus*, *Zapus princeps,* and *Sorex* spp. Additional information regarding sex ratios and Peterson Index, as well as species diversity and relative abundance of each species for the different habitat types and elevations, was filed at Yellowstone National Park.

Title: **Food Habits and Habitat Use of the Yellowstone Grizzly Bear**

Principal Investigator: Dr. Charles Schwartz (former PI Dr. Richard Knight, now retired)
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Forestry Sciences Lab
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Bozeman, MT 59717

Additional Investigators: Mark Haroldson, Shannon Podruzny

Objectives: To determine habitat requirements for the Yellowstone grizzly bear and to document its return to free-ranging status.

Findings: These 1998 data include information collected by the Interagency Grizzly Bear Study Team (members include USGS-BRD, YNP, WYDGF, IDFG, MTDFWP, USFWS, USFS) for the entire Greater Yellowstone Area. Data obtained within YNP is not broken out separately.

Surveys to determine an index of spring ungulate carcass availability were conducted during May. Approximately 300 km of survey routes were walked in four different ungulate wintering areas. Results were 0.13 carcass/km of survey route, indicating a relatively mild winter and small number of winter killed ungulates available to bears. Surveys of numbers of spawning cutthroat trout and their use by grizzly bears were conducted from mid May to early August. Spawner numbers were high in most streams surveyed. Data from grizzly bear tracks associated with cutthroat trout use suggested approximately 43 different grizzly bears were using this seasonal food. Three hundred hair samples for DNA analysis were collected from bears fishing spawning streams and will be used to provide an additional estimate of the number of individual grizzly bears that fish for spawning cutthroat trout. Surveys of 19 whitebark pine cone productivity transects were completed during July. Mean number of cones per tree was 8.4, indicating an average cone production year. A quantitative description of vegetative characteristics was completed at 105 grizzly bear radio-telemetry locations. Evidence of grizzly bear use was observed at 64 of these sites. Two hundred and fifty scats were collected and will be analyzed to identify food items used.

Title: **Population Dynamics of the Yellowstone Grizzly Bear**

Additional Investigators: Ms. Bonnie Blanchard, Mark Haroldson

Objectives: To describe the population trend from threatened status to recovery, and approximate stability.

Findings: These 1998 data include information collected by the Interagency Grizzly Bear Study Team for the entire Greater Yellowstone Area. Data obtained within YNP is not broken out separately.

Thirty-five individual grizzly bears were captured a total of 40 times during the 1998 field season. Eight captures occurred because of nuisance activity by grizzly bears requiring a management response by appropriate agency personnel. A total of 786 aerial radio locations were obtained on 58 individual grizzly bears that were radio monitored during all or some portion of the year. Thirty-five unique females with cubs of the year were identified. A total of 70 cubs were observed during the initial sightings of these females. Nine 1-cub, seventeen 2-cub, and nine 3-cub litters were observed. Mean litter size was 2.0. Females with young (cubs, yearlings, or 2-year olds) were observed in 15 of 18 Bear Management Units within the Greater Yellowstone Area. A total of six known grizzly bear mortalities occurred during 1998. Three of the six were human-caused, two were natural, and one is currently under investigation. Of the three human-caused grizzly bear mortalities, two were management removals of bears involved in sheep depredation that occurred well outside the USFWS Grizzly Bear Recovery Zone.

Yellowstone Grizzly Bear Investigations for 1995-1997 are now available at http://www.mesc.usgs.gov/yellowstone/. The 1998 Annual Report will be available by May 1999.

MICROBIOLOGY

Title: **Bacteria in Carbonate Hot Springs**

Principal Investigator: Dr. Carlton Allen
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Additional Investigators: Dr. Joan Combie, Dr. Fred Albert

Objectives: Identify bacteria in highest-temperature regions of carbonate hot springs; relate these bacteria to those found in other hot springs worldwide and to possible fossil bacteria in rocks from the planet Mars.

Findings: Carbonate hot springs support several species of thermophilic microbes at temperatures as high as 72 degrees C. These may be rapidly fossilized but are poorly preserved. Organic biofilms and possible nanobacteria, as well as morphologically and mineralogically distinctive carbonate rock fabrics, are more enduring biomarkers.

Title: **Thermophilic Diatoms from Alkaline and Acidic Hot Springs and Geysers in Yellowstone National Park**

Principal Investigator: Dr. Ken Andrews
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Colorado Springs, CO 80903

Objectives: To determine the density and diversity of thermophilic diatoms (Eukarya) growing in selected alkaline and acidic hot springs in Yellowstone National Park.

Findings: Samples from Cyanidium Creek and Sylvan Hot Springs containing functional diatoms were

used as inocula into a variety of acidified mineral salts media which were then incubated at the appropriate temperature. Sample temperatures ranged from 20 degrees C to 50 degrees C, and the pH ranged from 1.5 to 4.0. In mineral salts media supplemented with vitamins, much better diatom growth occurred, although none of the cultures sustained diatom growth for more than one or two generations. We are currently searching the literature for more algae enrichment media to be used on inocula taken from samples to be gathered this spring and summer.

Title: **Bacteria Living at Low pH and High Temperature**

Principal Investigator: Dr. Rick Bizzoco
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San Diego State University
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San Diego, CA 92182-4614

Objectives: Discovery of new hyperthermal acidophiles

Findings: We have identified seven new organisms in our electron microscopic analysis. Phase-contrast microscopy has revealed more than 50 morphological types in the hot springs we have examined. DNA staining was performed to document that the forms observed indeed were biological entities and/or living microbial cells.

Title: **Transition between Lithoautotrophy and Chemoheterotrophy in *Sulfolobus* Species.**

Principal Investigator: Dr. Paul Blum
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Lincoln, NE 68588-0666

Objectives: The goal of this project is to understand the evolutionary origin of the saccharolytic genes in *Sulfolobus*.

Findings: No findings in 1997 or 1998.

Title: **Molecular Ecology of Photosynthetic Hot Spring Bacteria that Resemble *Heliothrix oregonensis***

Principal Investigator: Dr. Sarah Boomer
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Monmouth, OR 97361

Objectives: The goal of research in our lab is to survey thermal areas for new representatives of hot spring bacteria that resemble *Heliothrix oregonensis*. Using molecular methods, we are isolating DNA from mat samples containing *Heliothrix*-like bacteria, amplifying the 16S rRNA gene, and characterizing this gene at the sequence level. Sequence information will be used to identify and classify novel strains, determining their precise relationship to *Heliothrix*.

Findings: Over the summer of 1998, undergraduate students and I surveyed twelve thermal areas in the park, identifying nine sites that harbored *Heliothrix*-like bacteria. These areas include mats in the Lower, Middle, and Upper Geyser Basin, and at West Thumb. Criteria for preliminary assessment included mat environment, microscopic analysis, and pigment absorption spectra. Since visiting the park, we have isolated DNA from one site, Hillside Springs, amplified 16S rRNA genes using PCR methods, and cloned representative sequences. Hillside clones are awaiting sequence analysis at present. Research students have just begun similar work on Fairy Springs material.

Title: **Fluorinated Organic Compounds in the Water and Biota of Hot Springs in Yellowstone National Park**

Principal Investigator: Dr. Thomas Bott
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Additional Investigators: Laurel J. Standley, Charles Driscoll

Findings: Due to personnel and funding problems, the proposed research effort could not be accomplished. We hope to be able to begin work during the summer of 1998.

Title: **Study of Thermophilic Microorganisms from Yellowstone National Park**

Principal Investigator: Dr. Jeff Braman
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Objectives: Identify unique 16S ribosomal RNA genes by nucleic acid sequencing of cloned DNA obtained from biomass collected at Yellowstone National Park.

Findings: Complete nucleotide sequence analysis of three cloned 16S ribosomal RNA genes were completed. One clone was retrieved from an Octopus Spring source pool archael 16S PCR product library (OSS16S10). The other two clones were retrieved from a Nymph Creek archael 16S PCR product library (N16S1 and N16S4). A preliminary search of the Ribosomal Database Project nucleotide database indicates that clone OSS16S10 has a 66% sequence match with an unidentified crenarchaeote 16S ribosomal RNA gene; clone N16S1 has a 49.5% sequence match with a Pph. oshima 16S ribosomal RNA gene; and clone N16S4 has a 52.7% sequence match with another unidentified crenarchaeote 16S ribosomal RNA gene.

Title: **Chemistry, Gas Fluxes, and Microbiology of Selected Cold Spring Areas in Yellowstone National Park**

Principal Investigator: Dr. Jean Brenchley
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Additional Investigators: Dr. Susan Brantley

Objectives: An objective of this project was to form an interdisciplinary team that would integrate the knowledge from two widely separated disciplines, microbiology and geology. The purpose of this team was to examine environmental conditions in Yellowstone National Park, including geochemical measurements, gas flux quantification, and indigenous microbial life. The project was designed to allow beneficial exchange of knowledge between two specialized fields, in addition to allowing the students involved to expand their horizons beyond the courses typically offered in their respective disciplines.

The collaboration of the faculty involved would establish communication lines for future studies. The scientific goals of the project were twofold. One goal was to measure geochemistry and quantify the gas fluxes in the Mud Volcano area of Yellowstone National Park. The second goal was to collect samples from these areas that would be used to isolate microorganisms. Of special interest were the cold springs at Yellowstone. Other microbiologists have examined microorganisms from the hot springs, but no one has isolated or characterized different species found in cold water springs. The long term goal of the project was to study microbial isolates from Yellowstone and determine what impact these psychrophilic (cold-loving) organisms have on the geochemistry of their environments.

Findings: The major success for the microbiologists involved in this project has been the isolation of several different organisms from samples collected at Yellowstone. Water, soil, and sediment samples were obtained from cold springs in the park. All of the sites sampled had temperatures of 18 degrees C or below, and many came from acidic environments or had high concentrations of gasses venting through the soil. We believe that this is the first exploration of microorganisms living in the cold-springs at Yellowstone. Eighteen organisms were isolated on media with pH values similar to the environments from which they were taken. Further biochemical characterization has been done on two of these organisms: Y-MV.4 and Y-MV.6. Both bacterial isolates were taken from sediment on the side of a cold water fissure where gas was being released. This sediment had a pH of 5.23 and a temperature of 18 degrees. Y-MV.4 is a Gram negative rod, and phylogenetic analysis of the 16S rRNA gene sequence has indicated that it is most similar to *Zoogloea ramigera*. Unlike other members of the *Zoogloea* genus, Y-MV.4 grows well at 4 degrees C, and forms colonies which contain a dark purple pigment. Y-MV.6 has milky white, shiny colonies, and microscopic examination has shown that it is a Gram positive coccus. Studies characterizing important enzymes from these isolates are currently underway.

Title: **Establishment of Laboratory Cultures of "Koreachaea" from Yellowstone**

Principal Investigator: Dr. Clifford Brunk
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Objectives: The objective of this project is to establish a laboratory culture containing bacteria and archaea from the Obsidian Pool in Yellowstone National Park. Once established, subcultures will be developed to simplify the complex population of organisms found in the original sample. The intent is to produce a relatively simple population of organisms so that individuals can be characterized.

Findings: We have established a laboratory culture and are beginning to determine the spectrum of organisms present.

Title: **Adaptations of Cyanobacteria to High Solar Irradiance: UV-Shielding Compounds**

Principal Investigator: Dr. Richard Castenholz
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Additional Investigators: S. Brenowitz, C. Wingard

Objectives: The first objective of the currently funded project is to evaluate the role of "sunscreen" (UV-absorbing) compounds in increasing the fitness of cyanobacteria exposed to high solar irradiance. In terms of biology of cyanobacteria, the possession of such compounds (e.g., syctonemin) may be the principal characteristic that allows numerous species to live in shallow benthic habitats (such as hot springs), and as terrestrial and semi-terrestrial crusts and mats.

A second objective is to determine the short-term detrimental effects of UV radiation on photosynthesis and other metabolic processes under natural but high fluence rates, comparing species of cyanobacteria that have no known "sunscreen" components with those that do.

A third and final objective for the 3 year study is to evaluate the role of UV radiation as an inductive agent that controls the regulation of light-harvesting photosynthetic pigments, or serves as a cue for the high light "escape" strategy of many motile cyanobacteria that move vertically within microbial mats.

Findings: In the summer of 1998, field experiments were run in Yellowstone on two natural mats of *Calothrix* sp. (a cyanobacteria), one of which contains high levels of scytonemin while the other does not. In June, experiments were run repeated experiments conducted in the summer of 1997. These were designed to determine if these field populations were optimally adapted to their UV environment and to provide the first test of the beneficial acclimation hypothesis using a field population. The beneficial acclimation hypothesis predicts that organisms exposed to given environmental conditions for a period of time will perform better under that set of conditions than cells acclimated to other conditions. By acclimating portions of mat under four different UV-excluding filters, treatments for a period of two to three days and seven to eight days, and then running photosynthetic experiments with cells under all four filter types, we were able to generate a 4X4 treatment design to determine if this hypothesis held true for these populations. Analysis suggests that this hypothesis does not hold for UV-photoinhibition in these cells. Release from UV stress was the overriding determinant in both the acclimation and photosynthetic treatments, so that cells performed better photosynthetically during experiments with complete UV exclusion regardless of their acclimation conditions. Thus, these cells do not appear to be optimally photosynthetically adapted to the light environment that they experience during the summer months. The overall pattern of acclimation and experimental response seems to be the same in the two springs, with all types of acclimated cells from both populations showing photosynthetic inhibition after incubation under UV-transmitting filters. However, some differences

between the scytonemin-rich mat and low-scytonemin mat were found. Specifically, overall photosynthetic rates were lower for the high-scytonemin mat, which may indicate that it is under greater stress. However, the degree of photosynthetic inhibition is lower for the scytonemin-rich cells compared with the low-scytonemin cells.

During the August trip, similar experiments were run using cells that had been acclimated for a period of ~60 days in Yellowstone during July and August. These experiments were designed to test the effect of long term acclimation to the various filter treatments on the two populations of cyanobacteria. A YNP ranger was able to periodically check on the condition of the filters during this 60-day period. Photosynthesis experiments under the same four filter treatments were run. Preliminary evidence shows a similar pattern to the short-term experiments, suggesting that the cells are still under UV stress at the end of the summer.

Title: **Heat Stable Enzymes from Thermophiles**

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Additional Investigators: Dr. Fred G. Albert

Objectives: The 1997 objective was to isolate microorganisms that produce heat stable enzymes. Alkaline phosphatase was of particular interest. The 1998 objective was to design a novel bioreactor to recover microorganisms that are considered to be "unculturable."

Findings: Microorganisms were found which produced heat stable alkaline phosphatase. However, the specific activity was insufficient to be of interest. Therefore, work was initiated in the laboratory to increase the specific activity while maintaining the thermal stability. High specific activity alkaline phosphatase has been produced; the effect on heat stability remains to be tested.

A small bioreactor was designed to account for many of the variables encountered under field conditions. This reactor is approximately 1 x 3 cm in size and allows for temperature control, constant water flow, and thus also constant removal of waste products. Two samples were collected and introduced into this reactor. Next year, these two samples will be analyzed to determine if any previously uncultivated microorganisms were obtained.

Previous work had looked at heat stable enzymes. This was a newly funded project and is now titled: A Mat Bioreactor to Recover "Unculturable" Organisms.

Title: **Biofiltration Processes Using Thermophilic Bacteria**

Principal Investigator: Emil Dombroski
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Objectives: 1.) To collect water samples containing sulfur-oxidizing thermophilic microorganisms. 2.) To select for sulfur-oxidizing organisms using a variety of liquid and solid media. 3.) To isolate and identify isolates that exhibit good growth characteristics on solid media. 4.) To inoculate isolates onto biofilters and evaluate their ability to remove hydrogen sulfide from a contaminated air stream.

Findings: Samples were collected from 16 different sites from the Norris Geyser Basin, Mud Volcano, Sylvan Springs, and Roaring Mountain areas. The temperature and pH of each sample was recorded at the time of sampling. Samples were inoculated into a variety of liquid media including S6 Medium for *Thiobacilli* (ATCC 290), Sulfur Medium, *Sulfolobus* Medium (ATCC 1256), Revised *Sulfolobus* Medium (RSM) (ATCC 1723), *Sulfolobus solfataricus* Medium (ATCC 1304), and *Thiobacillus thermosulfatus* Medium and were then incubated at 75 degrees. Based on observed growth under desired conditions, samples collected from two sites that had pH readings of 1.5 and less than 1, and temperatures of 77 degrees C and 90 degrees C, respectively, were chosen for further study.

Using a modified RSM (from which the tryptone and yeast extract was excluded), direct counts of up to 6.4 x 10E5 cells/ml were observed. The method (9216 B.) for performing the direct total count using epifluorescence and acridine orange as the fluorochrome was as described in "Standard Methods for the Examination of Water and Wastewater" 18th Edition, 1992. These numbers were sometimes difficult to maintain after several transfers in media that did not include yeast extract. Attempts to culture these microorganisms on solid media using Phytagel as the gelling agent were unsuccessful. The ability to isolate a microorganism that would grow on a solid support matrix is essential for its application to the biofiltration process.

Although we were able to culture some sulfur-oxidizing microorganisms at high temperatures, we were unable to isolate and identify any potential candidate microorganisms that fulfilled all of our requirements under the conditions tested. The project has been terminated at this point.

Title: **Biosedimentology, Microbiology, and Geochemistry of Modern Hot Springs**

Principal Investigator: Dr. Jack Farmer

See Geology

Title: **Protein Comparison of Thermophiles and Oral Bacteria**

Principal Investigator: Dr. Richard Gregory
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Objectives: Oral bacterial microflora are extremely diverse (more than 300 different species in the normal oral cavity) and have to survive relatively large temperature and nutritional variations. Thermophilic microorganisms have been fairly well described, but no comparison has been reported with oral bacteria. It is proposed here to compare protein antigens between thermophilic and oral bacteria by immunological and electrophoretic (protein size) techniques. SDS-PAGE electrophoresis will be used to compare the sizes of proteins between representative thermophiles and laboratory strains of oral streptococci (primarily *Streptococcus mutans*, the causative agent of human dental caries). Immunological assays such as ELISA and western blots will be used to compare reactivity between antibodies to protein antigens on *S. mutans* and the thermophiles. It is anticipated that similar proteins will be observed between thermophiles and oral bacteria, implying a possible common ancestry.

Findings: Bacterial colonies were isolated on both selective and non-selective petri plates. Selected colonies were propagated and stored frozen until assayed. Samples are currently being collected from human volunteers to compare to park samples. It is anticipated that more park samples will be required due to poor growth of several bacterial colony types upon secondary propagation.

Title: **Collection of Thermophilic Microorganisms**

Principal Investigator: Dr. Mathew Grossman
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Additional Investigators: Roger Prince, Richard Bare

Objectives: Identification of thermophilic hydrocarbon and organic and inorganic sulfur-compound degrading microorganisms.

Findings: In 1997, samples from various hot springs where used in enrichment cultures designed to obtain microorganisms able to oxidize a mixture of inorganic and organic sulfur compounds, including hydrogen sulfide and mixed mercaptans. Current activities are focused on evaluating the extent to which the mixed sulfur substrates are being attacked.

Title: **Collection of Microorganisms from the Thermal Springs and Pools at Yellowstone National Park**

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Additional Investigators: Bill Adney, Todd Vinzant

Objectives: Discover new microorganisms in hot springs water samples that produce industrially useful proteins, especially polysaccharide degrading, thermal tolerant enzymes.

Findings: During the past year, we have continued to study the cellulase enzymes produced by the acid tolerant thermophile discovered in Norris Geyser Basin hot springs in 1985, *Acidothermus cellulolyticus*. We have identified three endoglucanases and one beta-glucosidase in culture broths of *A. cellulolyticus*. All are moderately thermal stable, i.e., Topt = 75-85 degrees C. We are now studying the genes that code these enzymes and have sequenced the entire coding sequence for the most useful enzyme, endoglucanase EI. EI has been subjected to X-ray crystallography by A. Karplus at Cornell University and the 2.4 Angstrom structure published in Biochemistry.

Title: **Enrichment Isolation of P-III Assimilating Archaea from Yellowstone Hot Springs**

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Additional Investigators: George Felbeck

Objectives: To obtain organisms able to live by the oxidation of P-III compounds like phosphite (HPO_3) and to study the mechanism and energetics of that process. There is reason to suggest that such processes were features of early prokaryotic evolution.

Findings: We obtained, by enrichment, one organism capable of using phosphite as sole source of phosphorus. Based on lipid analysis of its membrane fraction, this organism proved to be a thermophylic eubacterium (ie. not archaeal), and the organism turned out to exhibit little in the way of interesting metabolic capabilities. For these reasons we are not continuing the study of this organism.

Title: **Differentiation of Brucellosis Vaccine RB51 from *Brucella abortus* Isolated from Cattle, Bison, and Elk**

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Additional Investigators: Norman Cheville, Janet Payeur

Objectives: The study is designed to evaluate phenotypic and genotypic characteristics of the brucellosis vaccine strain RB51. Objectives are to assess the stability of RB51 as determined by the use of genomic fingerprint, oxidative metabolism, and colonial morphology, and to differentiate this strain from isolates of *Brucella* from cattle, bison, and elk.

Findings: Brucellosis vaccine RB51 has a unique genomic fingerprint which distinguishes it from *B. abortus* isolated from cattle, bison, and elk. RB51 showed no change in characteristic patterns of oxygen

uptake on selected amino acid and carbohydrate substrates. RB51 maintains rough characteristics after in vivo and in vitro passages. RB51 is stable; distinct from *Brucella* isolated from natural cases of brucellosis.

Title: **Physiology and Geochemical Tracing of FeS/H2S Microorganisms in Subsurface Hydrothermal Environments**

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Additional Investigators: Dennis Grogan, Radu Popa

Objectives: To isolate and characterize anaerobic, pyrite-forming bacteria

Findings: We have isolated a Gram-negative bacterial strain capable of anaerobic formation of pyrite. We are currently characterizing the physiology of this strain and the minerological effects of its activities.

Title: **Heterologous Expression and Characterization of CYP119 from *Sulfolobus solfataricus***

Principal Investigator: Ms. Laura Koo
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Additional Investigators: Paul Ortiz de Montellano

Objectives: To identify natural substrates for CYP119, the first cytochrome P450 to be identified in archaebacteria. Water samples from *Sulfolobus* habitats will be extracted and screened for possible organic substrates.

Title: **Molecular and Functional Ecology of Hot Spring Photosynthetic Mats**

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Additional Investigators: Dr. Niels B. Ramsing, Dr. Ronnie N. Glud, Ms. Andrea Wieland, Dr. Kirsten Habicht

Objectives: The project combines modern microbiological, molecular biological, and ecophysiological methods for studying the microbial ecology of photosynthetic hot spring mats. The goal is to gain a better understanding of the structure and function of the photosynthetic community in hot spring microbial mats.

Findings: During the first field trip in summer 1997, extensive field measurements of photosynthesis and the physico-chemical microenvironment of hot spring microbial mats in Octopus and Mushroom Springs in the White Creek area were performed. The methodology was mainly based on the in-situ use of various microsensors (for oxygen, pH, temperature, and light). In combination with these measurements, a detailed sampling program was performed, where mat samples were taken for subsequent microbiological and molecular biological analysis. Part of this work was done in close collaboration with the group of Professor D. M. Ward, Montana State University, Bozeman, Montana.

Besides field measurements, more detailed microsensor measurements of temperature and light adaptation of the photosynthetic populations in the mats were done in the West Yellowstone laboratory of Prof. Wiegert, University of Georgia, Athens.

In addition to the work in mats from the White Creek area, a few pilot studies on microbial mats at Mammoth Hot Springs were performed with microsensors in a sulfidic spring at Bath Lake Vista.

The first field trip served mainly as a pilot study to investigate the performance of various experimental techniques under field conditions. Several studies of the regulation of photosynthesis in the hot spring mats were successful and, in combination with the samples taken for microbiological and molecular biological analysis, we hope to correlate the data on functional adaptation to the cyanobacterial population structure in the investigated mats. Currently, the collected data are being analyzed and the samples will undergo further processing.

The project activities in 1998 have concentrated on analysis of experimental data obtained during the

first field trip in 1997. An extensive amount of data describing the physico-chemical microenvironment of the photosynthetic populations in hot spring mats have now been acquired and, simultaneously, samples of the mat communities have been taken, which are under intensive analysis by microbiological and molecular techniques. The latter is mainly done within a collaboration with Prof. D.M. Ward. A comprehensive data set is now almost completed and will undergo final analysis and publication in 1999.

Some of the findings from the 1997 field trip have been studied in further detail in 1998 with lab cultures of thermophilic phototrophs, which were obtained from culture collections.

In August 1999, another intensive field campaign is planned together with Profs. D.M. Ward and D.A. Stahl. These collaborators will focus on microbiological and molecular studies of the photosynthetic populations in the hot spring mats, while my group will focus on studying their ecophysiology and the microenvironmental controls of microbial processes in the mats. For this, a variety of microsensors will be deployed in concert with techniques for measuring solute exchange and stable isotope fractionation.

Title: **Microbial Biodesulfurization**

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Additional Investigators: Mark A. Schneegurt

Objectives: To isolate microorganisms with unique metabolic activities allowing for the transformation of polycyclic aromatic compounds that may contain heterocyclic rings and related products from the petroleum industry.

Findings: Samples taken from the park in fall of 1997 have been used as inocula for enrichment cultures. The compounds of interest were provided as sole carbon, energy, or sulfur sources. Cultures were maintained under aerobic or anaerobic, mesophilic or thermophilic conditions with various inorganic additions (like sulfate). The enrichment cultures did not provide any isolates capable of transforming the compounds of interest. All of the biological materials obtained from this first set of park samples have been destroyed. New enrichment cultures will be started when fresh inocula are obtained.

Title: **Isolation of *Sulfolobus***

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Objectives: Provide graduate students with experience in the enrichment, isolation, and growth of thermophilic Archaea.

Findings: Water and mud samples were collected from Moose Pool. The pH was less than or equal to two and temperature ranged from 59 to 69 degrees C. Samples were transported on ice to lab. Microscopic inspection revealed bulbous granular cells. Enrichment was done in M9 medium with 0.01% yeast extract and 1% sulfur at 80 degrees C. Successful enrichments of *Sulfolobus*-like organisms were obtained. Long term storage was attempted. $CaCO_3$ was added and the sample stored at 4 degrees. Growth was successfully recovered. $CaCO_3$ and glycerol (25%) were added and the sample put at -70 degrees C. Growth could not be recovered.

Title: **The Structure, Facies, and Deposition of Siliceous Sinter Around Thermal Springs: Implications for the Recognition of Early Life on Earth and Mars**

Principal Investigator: Dr. Donald Lowe

See Geology

Title: **Bacterial Diversity of Thermophilic Anoxygenic Phototrophs**

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Objectives: The main objective of this research is to discover and isolate laboratory cultures of

anoxygenic (non oxygen-evolving) photosynthetic bacteria from thermal environments. Photosynthetic bacteria are model organisms for the study of basic problems in photosynthesis and thermophilic phototrophs are very desirable because of their thermostable photosynthetic machinery. The long-term goal of the research is to probe photosynthetic diversity in hot springs of various chemistries and temperatures to determine the physiochemical limits to photosynthesis. This includes isolating and characterizing new species of photosynthetic bacteria and studying their basic biological properties including physiology, biochemistry, and phylogenetic position in laboratory cultures. All cultures of thermophilic phototrophs from Yellowstone as well as New Zealand thermal springs have been deposited in the American Type Culture Collection (ATCC) for public access by any qualified individual. This is basic research; no commercial funding or research ties exist between this project and any for-profit organization.

Findings: In fall 1997, samples were collected of warm (approximately 40 degrees C) acidic sulfide springs along the Gibbon River for isolation of acidophilic purple photosynthetic bacteria. Organisms resembling the acidophilic phototrophic coccus *Rhodopila globiformis* were isolated along with positive enrichments for a smaller, rod-shaped anoxyphototroph. Several enrichments also yielded *Cyanidium*-like organisms (thermophilic red algae). It is concluded that despite their low pH (approximately pH 3), warm acidic springs may contain a variety of purple bacteria.

We have isolated several thermophilic anoxygenic phototrophs from Yellowstone thermal springs, including *Chromatium tepidum* (ATCC 43061) and *Heliobacterium modesticaldum* (ATCC 51547). *Chromatium tepidum* has been of great biophysical interest because of its novel extremely long wavelength light-harvesting bacteriochlorophyll a complex, a photosystem unique to this organism. *Heliobacterium modesticaldum* is of interest because it is an endospore-forming photosynthetic bacterium (the first discovered) and is widespread in neutral to alkaline Yellowstone hot springs up to 60 degrees C. But perhaps the most notable of all of our thermophilic phototrophs is the green bacterium *Chlorobium tepidum* (ATCC 49652). Although not discovered in Yellowstone, this New Zealand hot spring phototroph grows extremely fast and has had its complete genome sequenced, the first photosynthetic bacterium to have been done so. Enrichment cultures for new thermophilic phototrophs from Yellowstone and elsewhere are in progress.

Title: **Molecular Diversity of Yellowstone Ecosystems**

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Additional Investigators: Dr. Martin Keller, Dr. Doris Hafenbradl, Dr. Jay Short

Objectives: Research efforts will be directed toward understanding the biological and biomolecular diversity within Yellowstone National Park. Working in close association with YNP personnel, Diversa Corporation will conduct a molecular survey of the phylogenetic and biomolecular diversity found within the microbial communities residing within Yellowstone's geothermal, terrestrial, and aquatic ecosystems. Coupled with this molecular taxonomic survey, Diversa scientists will employ recombinant techniques to screen environmental samples for relevant biomolecules. Both parties agree that this survey serves both the commercial and scientific interests of the corporation and the conservation purposes of the park. Yellowstone will provide Diversa with information that the park has generated and managed over many years to assist in the cooperative selection of unique and novel habitats. Diversa Corporation will provide the park with information pertaining to molecular diversity parameters measured within the park.

Findings: During FY97, Diversa scientists collected environmental samples from the following regions within Yellowstone: Heart Lake, Norris Geyser Basin, Octopus Springs, Five Sister Springs, and Obsidian Pool. Nucleic acids were isolated from many of these samples and some have been captured in the form of 16S and environmental DNA libraries. Work in progress includes sequencing of unique 16S clones and construction of phylogenetic trees, as well as ongoing screening of the environmental libraries for clones expressing a variety of enzymatic activities.

This Yellowstone research program has been ongoing since the inception of Diversa in May of 1994. Recently, the research has been elevated to the status of a CRADA. Soil, water, and sediment samples were collected from habitats ranging from a diversity of geothermal ecosystems, microbial mats, subalpine forests, riparian habitats, sedge marshes, alpine tundra ecosystems, bogs, swamps, streams, and lakes. The results will be refined and presented in annual reports, peer-reviewed scientific journals, and other appropriate reports.

Title: **Characterization of Microbial Rhizosphere Population of Acid and Thermotolerant Grasses Associated with Hot Springs in Yellowstone National Park**

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Additional Investigators: Mark Young, William Inskeep, Jon Wraith

Objectives: 1.) Collect plant and soil samples. 2.) Isolate and identify microbes associated with

thermotolerant grasses. 3.) Determine symbiotic relations of microbes with thermotolerant grasses. 4.) Isolation of extreme thermophiles and characterization of microbial diversity in extreme thermal soils.

Findings: Preliminary characterization of a heat and acid tolerant grass. Molecular analysis suggests significant total microbial diversity and metabolically active diversity in thermal soils. Isolation and characterization of extreme thermophilic bacteria (65 degrees C or greater) from these thermal soils is in progress.

Title: **Collection of Thermophilic Sulfur-Oxidizing Bacteria**

Principal Investigator: Ms. Ritva Muhlbauer
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Additional Investigators: Dr. E. Lawson

Objectives: To isolate thermophilic sulfur-oxidizing bacteria for 16S rRNA sequencing and characterization, as well as to determine their ability to degrade sulfide minerals in terms of sulfate generation and the dissolution of heavy metals at high solids concentrations.

Findings: None, as sampling has not been carried out to date due to unforseen circumstances. It is hoped that sampling will be conducted in 1999 as soon as the new permit is issued.

Title: **Microbiology of Hot Acid Springs**

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Additional Investigators: Susan B. Olson, Tom Clark

Objectives: Obtain novel strains of microorganisms capable of oxidizing metal sulfides in hot acid

solutions.

Findings: Small samples of water and sediment were collected in August 1997 from two hot acid pools in the Shoshone Lake Geyser Basin. The samples were transported to Little Bear Laboratories, Red Lodge, Montana. The samples were inoculated into culture media selective for growth of acidic, thermophilic microorganisms capable of oxidizing sulfide minerals. Culture media were incubated for one week under aerobic conditions at 65 degrees C. Large numbers of spherical microorganisms were observed microscopically in enrichment cultures. These enrichment cultures have been stored in the refrigerator. Additional tests of sulfide ore biooxidation by these cultures are planned. However, this test work has yet to be performed.

Title:	**Phylogenetic Analysis of High-Temperature Ecosystems**
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Additional Investigators:	C. Blank, K. Harris, E. Lyons, S. Dawson

Objectives: To characterize phylogenetically the constituents of high-temperature microbial communities without cultivation. The approach uses molecular techniques of cloning and sequencing ribosomal RNA genes and diagnostic hybridization probes.

Findings: Analyses continue on selected hot spring organisms and biofilms. Current, ongoing studies of rRNA clones from Octopus Spring 93 degrees C sinters have recently identified a new deepest divergence in the bacterial line of descent (C. Blank), branching earlier than the Aquificales lineage. Ongoing studies of Obsidian Pool have found that bacterial rRNA genes outnumber archaeal genes 50:1 in this 75-95 degree, high FeS environment. Many new lineages have been discovered.

Title: **Ecology of Phototrophs in High Iron Habitats**

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Additional Investigators: N. Parenteau

Objectives: To detect and characterize phototrophs in high iron environments, especially those that use reduced iron in photosynthesis. To determine the role of photosynthetic prokaryotes in thermal habitats and specifically in high iron thermal habitats.

Findings: We continued our studies on Chocolate Pots hot springs. Water analyses and newly refined microelectrode studies on the major phototrophic mat communities and non-phototrophic sediments confirmed that the phototrophs are substantially raising the oxygen and pH levels in the sediments they occupy, thereby potentially enhancing the rate of iron oxidation. Levels of oxygen in water flowing over the mats and in sediments devoid of cyanobacteria remain below air saturation levels, while those in cyanobacterial dominated sediments are double the air saturation levels. Evidence for the presence of anoxygenic phototrophs in sediments was found, as well as good near infrared light penetration to depths of 2.0 mm in plain sediments and in cyanobacterial mats. The possibility of well-developed photoferrotrophic communities exists in these springs.

In collaboration with RW Castenholz, eight cyanobacterial cultures have been obtained from these high iron springs. None seem to be dependent on the inclusion of extra iron in their growth medium.

Confocal laser scanning microscopy was used to study the iron mats while intact, and confirmed the presence of a highly layered iron and mat structure. The filamentous cyanobacteria were seen entwined among the iron particles confirming their role in binding and trapping the iron deposits.

In 1998, enrichment cultures have revealed evidence for the presence of purple photosynthetic bacteria that may be photoferrotrophs in the high iron sediments of Chocolate Pots hot springs. Very high iron-stimulated photosynthetic rates in the *Synechococcus* and *Chlorofexus* mats suggest possible photoferrotrophy in the *Chloroflexus*. Electron microscopy revealed that cyanobacteria are encrusted in iron in these springs. CLSM showed that filamentous prokaryotes bind and trap the iron sediments. Work is ongoing.

Title: **Isolation of Thermophilic Microorganisms from Yellowstone National Park**

Principal Investigator: Dr. Robert Ramaley
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Department of Biochemistry and Molecular Biology
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Omaha, NE 68198

Objectives: To determine the presence and ecological significance of the populations of thermophilic microorganisms of the Greater Yellowstone Ecosystem. To obtain additional thermophilic microorganisms for microbial and biochemical studies, including the purification of thermostable enzymes.

Findings: During the 1998 season, a few samples were obtained on May 10 from the Artist Paint Pot thermal area. The runoff channels from the springs at the base of the bluff contain high temperature filamentous streamers that are similar in EM morphology to the pink filamentous streamer bacterial community of Octopus Spring, Twin Butte Overlook Spring, etc. A few selected enzymes have been partially purified from the filaments, although the primary bacterium has not been obtained in culture as has been reported for the pink filaments in Octopus Spring. A continued study is being conducted of additional thermophilic isolates, including a faculative anaerobic, sulfate reducing, spore forming bacterium that are unrelated to sterothermophilus type isolates and appear to be a major component in many hot springs, including Obsidian, and which will be reported at the 1999 American Society of Microbiology annual meeting.

Title: **An Inventory of the Microbial Diversity of Yellowstone National Park**

Principal Investigator: Dr. Anna-Louise Reysenbach
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Additional Investigators: Doel Rodriguez, Everett Shock, Gavin Chan

Objectives: 1.) Determine the microbial diversity and geochemistry associated with high temperature thermal springs in Yellowstone National Park. 2.) Study the microbial ecology of these high temperature communities.

Findings: We found that although some aspects of the geochemistry of the two sites that were studied, Calcite Springs and Obsidian Pool, were very different, the sites shared some of the same microbial diversity. Both sites are home to the newly proposed kingdom in the Archaea, the Korarchaeota, and the deeply diverging bacterial lineage typified by black filamentous organisms. At Calcite Springs, these communities actively fix carbon dioxide and oxidize hydrogen rapidly. They are able to fix nitrogen and have the potential for dentrification. Based on these parameters, we have a number of enrichments of organisms from this site. In addition, we isolated two novel iron-reducing bacteria from Calcite Springs.

We focused our research in 1998 at Calcite Springs. During the winter field work, we confirmed our in situ biological hydrogen oxidation rates. Clearly the communities at Calcite use hydrogen as an energy source. In the summer, we compared two different methods of studying nitrogen fixation, and the results of this research are still being analyzed. Additionally, we took extensive geochemical and molecular biological samples along temperature gradients in the streams. Initial results suggest that the ferric to ferrous iron ratios change, although the microbial community structure does not dramatically vary. In 1998, we were awarded an NSF grant to continue this research.

Title: **Isolation of Novel Thermophylic and Extremely Thermophylic Microorganisms**

Principal Investigator: Dr. Frank Robb
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Additional Investigators: Judy Brown, Elizayeta Bonch-Osmoloyskaya

Objectives: To isolate novel thermophilic and extremely thermophilic microorganisms with additional metabolic capability for: 1.) Utilization of carbon monoxide and methane as carbon and energy sources; 2.) Requirement for aluminum salts as growth cofactors. Upon isolation and characterization of these strains, we will return to Yellowstone National Park and determine the distribution and ecological associations of the microbial strains with these unusual metabolic characteristics.

Findings: We have isolated several microorganisms from Octopus Spring. Some show growth stimulation by CO, and one shows the same exclusive use of CO as sole carbon and energy source as the type species, *Carboxydothermus hydrogenoformans*. These strains produce hydrogen and require CO and, in some cases, pyruvate or acetate, from a sample removed from Biscuit Basin. The strains have been grown in 20l fermentation preparations and the 16S ribsomonal RNA sequence indicates that it is a high G+C Bacillus.

Title: **Analysis of Metal Resistance in Yellowstone Bacteria**

Principal Investigator: Dr. Frank Roberto
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Idaho Falls, ID 83415-2203

Additional Investigators: Dr. Barrie Johnson, Dr. Simon Silver

Objectives: Identify and characterize heavy metal resistant bacteria from thermal features within YNP

Findings: In 1997, sampling was performed at several acidic and neutral hot springs and pools within the park, including Obsidian Pool, Moose Pool, Calcite Springs, Mushroom Pool, and Octopus Springs. Laboratory enrichments and characterization are ongoing.

In 1998, additional sampling was performed in the Mud Volcano area (Moose Pool), Gibbon River (near Beryl Spring), and Roaring Mountain. Enrichments were performed to recover *Sulfolobus acidocaldarius* growing autotrophically. Only *Acidianus brierleyi* and *Metallosphaera sedula* were recovered under these conditions. It appears that recently published information indicating *S. acidocaldarius* is a heterotroph only may be correct. Additional experiments are being performed to confirm this. Results will be published in the near future.

Title: **Fungi from Geothermal Soils and Thermotolerant Plants**

Principal Investigator: Dr. Rusty Rodriguez
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Additional Investigators: Dr. Joan Henson, Dr. Regina Redman

Objectives: To determine if fungi exist and grow in acidic geothermal soils. To monitor annual changes in fungal community structure as influenced by soil temperature, moisture, and metal concentrations. To determine if fungi from these soils are tolerant to metals and if they can be used for the

bioremediation of polluted water and soil.

Findings: We have isolated fungi representing 20 genera from acid-rhyolite geothermal soils in Amphitheater Springs. The fungi represent thermophilic and thermotolerant species with the most thermotolerant species isolated from soils at 105 degrees C. The taxonomic status of these fungi is presently being determined by rDNA sequence analysis. In addition, we are currently monitoring the community structure of these fungi every three to four months. In addition, we are assessing the tolerance of these fungi to metals and the mechanisms of metal tolerance.

Title: **Evolution of Carbon and Nitrogen Metabolism in Microorganisms**

Principal Investigator: Dr. Lynn Rothschild
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Additional Investigators: Rocco Moncinelli, Lisa White

Objectives: Using microbial mats as modern analogs of precambrian ecosystems subject to elevated levels of carbon dioxide, pH, and UV radiation, we will determine how these microbial mat communities respond to each of these parameters individually and in combination.

Findings: We found that under elevated levels of carbon dioxide, C-fixation and denitrification rates increase. Further, we have shown that UVB directly inhibits denitrification, photosythesis, and DNA synthesis rates.

Title: **Subsurface Transport Mechanisms for High-Temperature Microbial Life and the Nature of the Subsurface Biosphere**

Principal Investigator: Dr. Michael P. Ryan
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Objectives: Determination of the transport mechanisms and the three-dimensional structure of thermophilic and hyperthermophilic microbial communities. The work is done in relationship to the structure(s) of the thermal intervals and isotherms of their optimal temperature range and limiting temperatures.

Findings: Galerkin-based finite-element numerical simulations have been completed for the determination of the flow velocity vectors and the thermal structure of theoretical end-member microbial transport scenarios. These include 1.) Continuous convective transport of microbes in fracture and microporous volcanic rock; 2.) Continuous convective transport in multiply-fractured volcanic rock.

These simulations have produced maps of two-dimensional slices through the subsurface of fractured volcanic substructures appropriate to the deep structure of Yellowstone's fracture-controlled hydrothermal conduits. In cross-section, the simulations depict the time-space evolution of the regions of stability for 1.) thermophilic microbes (50-80 degrees C); 2.) hyperthermophilic microbes (80-113 degrees C); and selected macromolecules (114-~200 degrees C). Manuscripts for journal publication reporting these and other general findings are now in preparation.

Title: **Epiphytic Bacteria of Grasses- *Pantoea herbicola***

Principal Investigator: Dr. David Sands
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Objectives: To collect epiphytic bacteria of grasses, specifically the ubiquitous plant bacteria *Pantoea herbicola*. To transform these bacteria with *Brucella* antigen to effectively inoculate park animals for

Brucella.

Findings: Several *Pantoea* isolates were collected and transformed with the calf scour antigen. This provides us with the necessary information to carry on towards the development of this bacterium transformed with the *Brucella* antigen. Funding for this project has been appropriated by the USDA APHIS and Small Business Association.

Title: **Isolation of Hyperthermophilic Archaea and Bacteria from Different Solfatara Fields in the World**

Principal Investigator: Dr. Karl Stetter
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Additional Investigators: Robert Huber, Wolfgang Eder, Gudrun Amann, Nicole Eis

Objectives: Isolation of new hyperthermophiles and investigations of hyperthermophilic biotopes

Findings: In 1997, members of the novel kingdom Korarchaeota had been identified only by analyses of 16S rDNA sequences obtained from Obsidian Pool samples. For the first time, we were able to cultivate Korarchaeota in a continuous lab culture at 85 degrees C. The morphology of the Korarchaeal member pJP27 was identified by whole cell hybridization. The organism was rod-shaped, sometimes slightly curved, and variable in length (5-10 um). Isolation of the Korarchaeota in order to obtain a pure culture and to investigate their biochemical and physiological properties is in progress.

Furthermore, the description of the novel hyperthermophilic isolate M11TL from the Obsidian Pool is accepted for publication. Sulfur-inhibited *Thermosphaera aggregans* sp. nov. is a new genus of hyperthermophilic archaea isolated after its prediction from environmentally derived 16S rRNA sequences.

During a 1997 field trip in Yellowstone, we took samples from the pink filaments, present in the outflow of Octopus spring at temperatures between 82-88 degrees C. For the first time, we were able to enrich and isolate a member of the pink filaments. The unique physiological and biochemical properties of the new isolate OC 1/4 were studied in detail. By 16S rRNA sequence analysis, the isolate belongs to the Aquificales. Within this order it represents the new genus *Thermocrinis*, with the type species *Thermocrinis ruber*.

Title: **Thermophilic Bacteria for the Modification of Fossil Fuels**

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Objectives: Examine the mechanisms by which thermophilic bacteria are able to modify organosulfur compounds in coal-derived materials.

Findings: No new findings this year.

Title: **Integrated Biogeochemical Database**

see Database

Title: **Bacterial Reduction of Chromate**

Principal Investigator: Mr. Chuck Turick
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Objectives: Isolate mixed cultures of facultative anaerobes from thermal environments capable of biological reduction of hexavalent chromate to trivalent chromium.

Findings: No work was done in this area in YNP during this reporting period.

Title: **The Collection of Thermophilic Methylotrophs**

Principal Investigator: Dr. Steve Vesper
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Cincinnati, OH 45268

Objectives: Our objective is to isolate microorganisms that can degrade TCE at high temperatures. These temperatures may be created in an electroosmotic environment.

Title: **Ecology of Hot Spring Microbial Communities**

Principal Investigator: Dr. David Ward
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Additional Investigators: M. Bateson, Dr. Mike Ferris, T. Papke, Dr. Michael Kühl, Mr. Marcel van der Meer, Dr. Jan de Leeuw

Objectives: The general objective of our research is to understand the distribution and activity of microorganisms inhabiting microbial mat communities in geothermal effluents. At the moment, we are particularly interested in understanding the composition, structure, and physiology of these mat communities as models of microbial communities in general. We are using ribosomal RNA (rRNA), intervening transcribed spacer (ITS), and lipid biochemical cell components to identify community members. In addition, we are attempting to evaluate whether the stable carbon isotope ratios of specific lipid biomarkers might help distinguish modern mat communities constructed by either cyanobacteria or green nonsulfur bacteria and, hence, their stromatolite counterparts in the fossil record.

Findings: The status of our project is ongoing. We have most recently been discovering diverse bacterial inhabitants of cyanobacterial mats occurring between 50 and 75 degrees C in the effluent channels of alkaline silicious hot springs, such as Octopus Spring and Mushroom Spring in the Lower Geyser Basin, using 16S rRNA gene sequences as biomarkers. This sequence data enables us to view the evolutionary history of the populations we detect. We have also recently used a technique called denaturing gradient gel electrophoresis (DGGE) to study the distributions of these populations along thermal and vertical gradients in such mats. The results suggest that many predominant populations of cyanobacteria and green nonsulfur bacteria which exist in such mats are closely related species which are adapted to

environmental parameters along these gradients (e.g., temperature and parameters, such as light, which vary in the 1 mm thick photic zone).

Other DGGE studies suggest that additional populations of cyanobacteria may be specialized as colonist species, which appear after physical disturbance to the photic zone. This is pertinent to how microbiological sampling impacts species distribution.

Microscopic image analysis studies have revealed that some pure-cultured *Synechococcus* isolates exhibit very slow motility by some sort of gliding mechanism. Such movements are presumably important in the spatial positioning of cyanobacterial populations under different light conditions.

Title:	**Ecology and Physiology of Novel Aerobic and Anaerobic Bacteria from Extreme Environments**
Principal Investigator:	Dr. J. Gregory Zeikus
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Additional Investigators:	Dr. Mahendra K. Jain

Objectives: 1.) Isolation and studies of thermophilic bacteria with hydrolyase activities. 2.) Isolation and studies on fermentative metabolism of thermophilic bacteria.

Findings: The adhB gene encoding *Thermoanaerobacter ethanolicus* 39E secondary-alcohol dehydrogenase (S-ADH) was cloned, sequenced, and expressed in *Escherichia coli*. The 1056 bp gene encodes a homotetrameric recombinant enzyme consisting of 37.7 kDa subunits. The purified recombinant enzyme is optimally active above 90 degrees C. An NADP(H)-dependent enzyme, the recombinant S-ADH has 1400-fold greater catalytic efficiency in propan-2-ol oxidation than in ethanol oxidation. *Thermoanaerobacterium saccharolyticum* B6A-RI beta-xylosidase, which belongs to family 39 of a general classification of glycosyl hydrolases, was purified as a recombinant enzyme from *Escherichia coli*. The stereochemistry of the hydrolsis of pera-nitrophenyl beta-D-xylopyranoside was followed by 1H NMR. The spectrum recorded after 2 h hydrolysis showed a large signal centered at 4.47 ppm (J approximately 10Hz) assignable to H1 of free beta-xylose with a small amount of alpha-xylose (5.05 ppm, J approximately 3 Hz) attributable to mutarotation. This result indicates that *T. saccharolyticum* beta-xylosidase operates with overall retention of the anomeric configuration. This result, with the lack of sequence similarity between the two families of beta-xylosidases, suggests that these two families have major differences in their active-site geometries. Consistent with its retaining mechanism, beta-

xylosidase of *T. saccharolyticum* B6A-RI also displayed transglycosylating activity: reverse-phase HPLC showed approximately 30% conversion of pera-nitrophenyl beta-D-sylopyranoside into a number of higher nitrophenyl oligosaccharides after five minutes of incubation with the enzyme. The structure of the most abundant oligosaccharides could be determined by total correlation spectroscopy NMR and showed that the enzyme can build beta-1,4; beta-1,3; and beta-1,2 linked xylo-oligosaccharides.

It is clear from the literature that thermozymes share catalytic mechanisms with their mesophilic counterparts. When cloned and expressed in mesophilic hosts, thermozymes usually retain their thermal properties, suggesting that these properties are genetically encoded. Sequence alignments, amino acid content comparisons, and crystal structure comparisons indicate that thermozymes are, indeed, very similar to mesophilic enzymes. Thermostability and thermophilicity molecular mechanisms are varied, differing from enzyme to enzyme. Thermostability and thermophilicity are usually caused by the accumulation of numerous subtle sequence differences.

ORNITHOLOGY

Title: **Ultralight/Whooping Crane Project**

Principal Investigator: Mr. Kent Clegg
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Grace, Idaho 83241

Objectives: To determine if whooping cranes released in the park could survive to migrate south in the fall and would return to the same area in subsequent seasons.

Findings: Two whooping cranes were released in the park and survived the summer to migrate south. Both whooping cranes migrated independently to New Mexico, but only one has been confirmed on the Bosque Del Apache NWR and the location of the other one is not known.

Title: **Movements of Bald Eagles in the Greater Yellowstone Ecosystem**

Principal Investigator: Mr. Alan Harmata
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Biology Department
Fish & Wildlife Program
Bozeman, MT 59717

Additional Investigator: Dr. George Montopoli

Objectives: Determine movements, survival, and turnover of bald eagles produced and nesting in Yellowstone National Park.

Findings: Two bald eagle nestlings banded in 1998.

Title: **Landscape Heterogeneity and Bird Diversity under Natural and Human Disturbances in the Greater Yellowstone Ecosystem**

Principal Investigator: Andrew Hansen

See Ecology

Title: **Effects of Forest Fires on Rocky Mountain Landbird Communities**

Principal Investigator: Dr. Richard Hutto
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Missoula, MT 59812-1002

Objectives: Examine extent to which various bird species are tied to early post-fire conditions.

Findings: Published in *Conservation Biology* 1995 9:1041-1058.

Title: **Yellowstone Birds: Their Ecology, Life Strategy, and Distribution**

Principal Investigator: Mr. Terry McEneaney
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Yellowstone National Park, WY 82190

Objectives: Document the life history, ecology, life strategy, and distribution of all birds documented in YNP.

Findings: Sufficient data has been collected to begin writing a report in 1999.

Title: **Ecology of Cavity-Nesting Birds: Influence of Forest Disturbance Type on Density, Breeding Success, and Dispersal**

Principal Investigator: Dr. Jay Rotella
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Bozeman, MT 59717

Additional Investigator: Nancy Hoffman

Objectives: Investigate the distribution, density, and breeding success of hairy, downy, three-toed, and black-backed woodpeckers in mature lodgepole pine forests (controls) and those disturbed by fire or timber harvest.

Findings: Distributions are closely tied to distributions of recently burned coniferous forest. Characteristics of nest sites were identified and quantified. Findings are presented in detail in Hoffman (1997) - M.S. thesis, Biology Department, Montana State University.

SOCIOLOGY

Title: **Interpretive Impacts from the Participants' Perspectives**

Principal Investigator: Ms. Elizabeth Barrie
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Objectives: The proposed study will investigate the nature and meaning of meaningful interpretive experiences by analyzing subjective accounts of recollected meaningful interpretive programs collected from visitors to two nationally significant interpretive sites. Studying the most meaningful interpretive encounters will provide insight into interpretation at its best for the participants. Based on the accounts of the informants in this study, a model of the elements of meaningful interpretive experiences will be developed which can be used to inform the creation and evaluation of interpretive programs.

Findings: Data collection for this study is still in the pilot testing phase. As of February 10, 1999, there have been no findings. A sample of visitors to Yellowstone National Park will be obtained during the summer of 1999.

Title: **Close Encounters: Factors Affecting whether People Approach Animals Closely in a National Park**

Principal Investigator: Dr. Robert W. Colman
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Objectives: The goal was to observe and videotape visitors who were observing large mammals so as to provide data about behavior in crowds to compare with similar observations at Yellowstone National Park in previous years. The larger study of which this work is a part is designed to explore regularities in human behavior in "animal jams," with a particular focus on social influence processes in crowd settings.

Findings: Observations and videotaping were carried out during several periods from late July to early September 1997. Work focused in particular on visitors observing male elk near Canyon Village. These were the same elk and the same locations that had given rise to rich observations in the 1996 season. Observations and videotaping were carried out during several periods from early to late July 1998. Work focused in particular on visitors observing animals near Seven Mile Bridge.

Consistent with earlier findings, the attractiveness of the animals, physical features in the immediate setting, and the behaviors of other people who were present contributed to the likelihood of people getting close to the animals. Study of the apparent effects of modeling is underway. The hypothesis is that the presence of a similar other person near an animal will increase the likelihood of close approach by a person or group newly arriving on the scene.

Title: **People and Nature: Yellowstone as Landscape**

Principal Investigator: Mr. Raymond Fenio
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Unionville, IN 47468

Objectives: The objective of this research is to undertake a systematic and comprehensive study of the people who visit, work, and reside in Yellowstone National Park. The research will focus on the cultural context in which Yellowstone is experienced and talked about. Past cultural contexts will be seen in historical data, and present cultural context will be discovered with empirical methods. Forecasting future cultural contexts of values that will affect Yellowstone is another objective.

Findings: This research is ongoing.

Title: **Pilgrims and Rituals in Yellowstone National Park: Touristic Encounters with the Sacred**

Principal Investigator: Ms. Sandra Nykerk
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Gardiner, MT 59030

Additional Investigator: Laurence Carucci

Objectives: Examine the relationships between visitors and perceptions of wilderness/nature as inculcated in Yellowstone National Park

Findings: Research is ongoing – 26 interviews with YNP visitors have been conducted to date and are in the process of being transcribed. Over 1,500 images of tourists have been obtained – mostly at Old Faithful. More than two hundred workprints have been produced. Several additional interviews and the photographic project will continue through the 1999 field season.

WILDLIFE MANAGEMENT

Title: **Spatial Ecosystem Modeling of Yellowstone Bison and their Environments**

Principal Investigator: Dr. Michael Coughenour
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Objectives: Estimates of ecological carrying capacity (ECC) for bison, and associated population responses, are needed to interpret past increases in bison population sizes and ranges, and to assess the risks of future increases and movements within and across park boundaries. It is unclear at present the extent to which population increases have been due to normal population growth responses to unused or undiscovered ECC, the nomadic tendencies of bison, or the plowing and grooming of roads and trails in the winter and resultant effects on bison movements, energetics, and survival. I will use spatial-dynamic modeling as a means to integrate these processes to provide broader explanations of past changes, and to provide a means to assess scenarios of possible outcomes in the future. I will use an existing spatial-dynamic ecosystem model to assess bison ECC. The model simulates plant growth, animal foraging, energetics, population dynamics, and spatial distributions over time. Over the first four years, I will coordinate with the other Yellowstone bison subprojects to synthesize data for use in the model. Most of the modeling effort will occur in the final year, when I will parameterize and test the model for the Greater Yellowstone Ecosystem.

Findings: Project has just commenced.

Title: **Development of Aerial Survey Methodology for Bison Population Estimation in Yellowstone National Park**

Principal Investigator: Dr. Robert Garrott
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See Mammalogy

Title: **Ecological Effects of Road Grooming on Bison in Yellowstone National Park**

Additional Investigators: Daniel Bjornlie

Objectives: To address the question of the impacts of groomed roads on the distribution, movements, and behavioral patterns of bison in the Madison-Gibbon-Firehole area of Yellowstone National Park, and help determine the factors that drive bison movements on groomed roads as well as off roads.

Findings: Mr. Bjornlie is currently in his second and final field season of the study. Bison trail monitoring, quantification of bison groomed road use, behavioral observations, and distribution and activity surveys are being conducted again this winter. No relationship was found between bison road use and snow depth. The number of bison groups traveling on roads increased in late December, leveled off, and then increased sharply in March after road grooming had ceased. Only 8% of observed bison travel during the road grooming period took place on groomed roads. Of bison groups observed traveling on roads, 75% (21 of 28) had negative reactions to interactions with visitors. A detailed annual report was distributed to all cooperators in October 1998.

Title: **Evaluating Risk Factors for Transmission of Brucellosis from Bison to Elk in Yellowstone National Park**

Additional Investigators: Matthew Ferrari

Objectives: The primary objective of this study was to assess the potential for inter-specific transmission of *Brucella abortus* between the bison and elk on the Madison-Firehole winter range. Secondary objectives were 1.) To determine the prevalence of sero-reactors in the Madison elk herd. 2.) To determine the level of association and contact between bison and elk during the winter and spring. 3.) To determine the factors that influence the level of association between the two species. 4.) To determine whether increased association between bison and elk leads to an increase in disease exposure.

Findings: We completed two field seasons between November 1996 - May 1997, and November 1997 - November 1998. Between the two field seasons, we collected over 2,500 locations of radio collared elk and conducted 30 ground censuses to determine bison numbers and distribution. We also have taken serum samples from 73 adult cow elk, and have received the results of tests for *Brucella* antibodies for 52 of those animals.

Analysis found that range overlap between bison and elk in the Madison-Firehole varied between 53-76% and tended to increase from December to May. Radio collared elk were found to be within 100 m of bison in 19% of telemetry locations between April and May, the peak time of bison calving. Regression analysis indicated that snow water equivalent, a measure of snow depth and density, was positively correlated with elk/bison association and was the strongest predictor of association. Despite the close association between the two species, a sample of 52 adult cow elk indicated that the prevalence of seropositive animals was not significantly greater from other elk populations that do not associate with bison.

Title: **Post-Burn Resource Selection, Physiological Condition, and Demographic Performance of Elk**

See Fire

Title: **Predator-Prey Dynamics in a Wolf-Ungulate System**

Additional Investigators: Rose Jaffe, Lee Eberhardt, Doug Smith, Kerry Murphy

Objectives: To examine the impacts on the ungulate populations from wolf predation in the Madison, Firehole, and Gibbon drainages of Yellowstone National Park. Specifically, predation rates, prey selection, and wolf hunting strategies according to landscape will be addressed. Aspects of prey vulnerability to be studied include species, sex and age class, condition of prey, landscape features, and snow conditions. The data collected will be used to help predict impacts of wolf predation on the prey populations.

Findings: Ms. Jaffe is in her first year of data collection. Travel routes and locations of hunts and kills are recorded through the daily ground tracking of wolves in the study area. This information will help determine wolf hunting strategies in relation to landscape features and prey distribution and abundance. Necropsies are preformed on every kill to ascertain the species, age, sex, and condition of the prey to study prey vulnerability and wolf prey selection. Detailed snow condition data are also collected by digging snow pits and recording snow layer information at hunt and kill sites to examine the possible effects of snow conditions on prey vulnerability and wolf hunting success. To attempt to determine prey encounter rates, locations of prey while tracking the wolves are recorded. The amount of data collected is determined by daily wolf activity.

Title: **Winter Recreation Effects on Wildlife in Yellowstone National Park**

Additional Investigators: Dr. Scott Creel, Amanda Hardy

Objectives: To assess the effects of winter recreation on wildlife populations in the Madison, Gibbon, and Firehole drainages in Yellowstone National Park. Specifically, to analyze elk and bison populations, distributions, behavior, and fecal stress hormone levels for possible spatial and temporal correlations to varying types and levels of human activity throughout the winter.

Findings: Currently in the first winter of field work, we are repeatedly and randomly locating 36 radio-collared cow elk, obtaining population, distribution, and behavioral data on the elk in the study area. We are conducting bison surveys in conjunction with another study ("Ecological Effects of Road Grooming on Bison in Yellowstone National Park") for bison population, distribution, and behavioral data. Fecal and urine samples from radio-collared elk, unknown elk, and unknown bison are being collected for analysis of glucocorticoid (stress hormone) levels and nutritional stress. Road, trail, and off-trail surveys are being conducted throughout the study area, documenting elk, bison, coyote, deer, moose, trumpeter swan, and bald eagle sightings, along with group size, distance from road or trail, behavioral responses to human activity, and types of human activities and behaviors present. All data are being collected for analysis in spatial and temporal schemes to detect possible variation related to winter recreation activities and levels or other confounding variables such as winter severity or nutritional stress.

Title: **Bison Forage Relationships in the Madison-Firehole Area of Yellowstone National Park**

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Additional Investigators: Peter Gogan, Steven Dawes

Objectives: 1.) To measure forage offtake attributable to bison in six sites in the Madison-Firehole area. 2.) To test the use of multispectral radiometry as a means of determining standing biomass and offtake.

Findings: In May, June, and August 1997, 120 1x1 m exclosures were monitored to determine differences between standing crop inside enclosures and in randomly selected plots outside exclosures. Only 8 of 48 paired t-tests (site by season by live vs. dead material) produced significant differences between dried weights of vegetation clipped inside and outside exclosures. Most differences occurred at

sites during the May sampling period and were the result of winter or spring use. Only the Terrace Springs site had significant differences in all clipping periods. Of the six sites monitored, only Terrace Springs had a detectable reduction in late summer biomass due to ungulate foraging. Multispectral Radiometer tests (ground and satellite) are still being analyzed. Road and fecal counts indicated reduced use of the Madison-Firehole winter area in summer 1997 compared to summer 1996, but these indices were not well correlated with estimated offtake of forage at individual sampling sites. Winter counts (November 1996-April 1997) of bison indicated that the Terrace Springs, Fountain Flats, and Interchange clipping sites received consistent use throughout winter. The four-mile site and the Midway Geyser Basin site received light use. The Gibbon Meadow site received little if any use.

Mr. Dawes completed his thesis in May 1998, and a final report was sent to YNP. We were able to use conventional range exclosure methodology to measure bison forage offtake. Grazed sites at heavily used sites averaged 3% less standing biomass than protected paired exclosures during the 1996 growing season, and 41% less in 1997. Early spring use reduced new growth by 44% at heavily used sites. In winter, bison apparently reduced standing biomass at heavily used sites by 23% (compared to protected plots). A reduction of bison numbers in the study area of >50% between the 1996 and 1997 growing seasons did not reduce offtake at sites they elected to use heavily. MSR tests provided the background for a park-wide estimate of standing biomass in herbaceous plant communities that was completed in summer 1998.

Title: **Determining Forage Availability and Forage Use Patterns in the Hayden Valley**

Additional Investigators: Dr. Peter Gogan, Mr. Thomas Olenicki, Dr. Robert Garrott

Objectives: 1.) Delineate seasonal forage use patterns by bison in the Hayden Valley. 2.) Determine long-term and short-term effects of ungulate foraging on vegetation in the Hayden Valley. 3.) Identify cost-effective monitoring strategies for monitoring impacts of ungulates on vegetation. 4.) Estimate annual production and standing crop available to ungulates in the Hayden Valley.

Findings: We initiated fieldwork in June 1998. Three sites were selected for monitoring bison use and offtake over a 3-year period using movable exclosures. Additional sites were selected for one year placement of exclosures. During summer - fall 1998, use and standing biomass were measured at randomly selected sites and at the three sites that will be maintained for three years. We obtained LANDSAT images (and did corresponding ground calibration) that will be used to estimate standing biomass in the study area during 1998. Data from 1998 are being analyzed. The project is proceeding on schedule.

Title: **Impacts of Roads on Movements and Habitat Use by Bighorn Sheep on the Northern Range**

Additional Investigators: Mr. John Mack, Mr. Kayhan Ostovar

Objectives: 1.) To identify movement patterns, seasonal ranges, and relationships among bighorn groups on the northern range. 2.) To determine how current roads impact movement and behavior. 3.) To identify areas that would be sensitive to new road construction.

Findings: Of 18 sheep captured and radio collared in 1997, 17 were alive with functioning radios as of February 1, 1998. One ewe was killed by a mountain lion in June. Five sub-populations have been identified on the lower portion of the northern winter range, with a total population of 70-80 animals. Lamb production in summer 1997 was high, but only four lambs were recruited to the wintering population. Sheep in one or more of these populations used areas adjacent to public roads throughout 1997. One unmarked ewe found outside Yellowstone was killed by a vehicle. Obvious impacts of roads on movements have been minor so far, but we are analyzing activity patterns, lungworm shedding, and fecal cortisol for sheep associated with roads for comparison with sheep not associated with roads to determine if less obvious effects are occurring.

Mr. Ostovar completed his thesis in December 1998 to complete the movement and road impact portion of the study. We found that sheep occupying the Everts winter range were organized into three ewe bands and two to three ram bands. One ewe band migrated to Mt. Washburn, another to Sepulcher Mountain, and the third remained semi-resident, moving up the Yellowstone Canyon in summer. Ram bands occupied summer ranges on Mt. Everts and Quadrant Mountain. Realignment of the present road from Gardiner to Mammoth to the east of the Gardner River would reduce disturbance to sheep, and realignment over McMinn Bench would increase disturbance. Reconstruction of the road over Dunraven Pass would have minor if any impact on sheep summering on Mt. Washburn.

Title: **Effects of Flooding and Browsing on Biomass and Nutrient Allocation Patterns in Two Species of Willow in Yellowstone National Park**

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Additional Investigators: Francis Singer

Objectives: 1.) Collect native willow species in YNP. 2.) Grow cuttings in the greenhouse for one to two

years to provide materials for browsing and flooding experiments. 3.) Conduct greenhouse experiments to determine the biomass and nutrient allocation patterns of *Salix* species in response to flooding and clipping treatments.

Findings: *Salix boothii* and *Salix bebbiana* cuttings were collected in Yellowstone National Park during late summer 1998 and transported to the greenhouse at the University of Wisconsin-Stevens Point. Cuttings were planted in tubes with potting materials and treated with root growth hormones. After six months, mortality of cutting was high (100% for *Salix bebbiana* and >70% for *Salix boothii*). Sufficient material does not remain to conduct anticipated experiments. Requests to collect additional materials prior to spring growth will be made. *Salix bebbiana* will not be collected in the future.

Title: **Grizzly Bear Aversive Conditioning Study, Bear/Livestock Interactions, Population Characteristics, and Habitat Use by Grizzly Bears in the Southern Third of the Yellowstone Ecosystem and Nuisance Bear Coordination**

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Additional Investigators: Mark Bruscino, Mark Ternent, Greg Holm, Chris Queen

Objectives: Minimize bear/human/livestock interactions. Coordinate relocations of nuisance grizzly bears with YNP in accordance with "Nuisance Grizzly Bear Guidelines". Determine extent of depredation on livestock. Relocate marked bears and replace telemetry collars to assess survivorship. Conduct aversive conditioning in specific conditions in conjunction with YNP bear management personnel. Jointly publish annual nuisance grizzly bear summary. Investigate use of hair sampling to monitor grizzly bear population.

Findings: The Wyoming Game and Fish Department captured 13 grizzly bears in 1998. None of these bears were captured under the current nuisance guidelines. As a result, no bears were relocated into Yellowstone National Park.

Title: **Epidemiology and Pathogenesis of Brucellosis in Yellowstone National Park Bison**

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Additional Investigators: Jack Rhyan, Keith Aune

Objectives: Determine the natural course of brucellosis in free-ranging bison. Determine modes of transmission. Provide information on the prevalence of infection and abortion.

Findings: Research into the epidemiology and pathogenesis of brucellosis in Yellowstone National Park bison began its first full year in 1997. During October of 1997, 18 new bison were added to the study in the western portion of the park between Old Faithful and the West Entrance. These additional bison compliment the 24 bison radio collared between 1995 and 1996 for a total of 40 study animals. Six of the 18 new bison (33%) card tested positive for brucellosis. Approximately 65% of the bison sampled during the fall of 1997 (Lamar and west side groups) were pregnant. Pregnancies were detected through rectal palpations and sonography.

We sample three times per year during the spring, fall, and winter. Samples collected include blood (serology and culture); nasal, conjunctival, rectal, and uterine swabs (culture); and milk (culture). Vaginal transmitters were placed into pregnant bison during our February 1997 sampling period to monitor parturition events during spring. These transmitters helped us to find birth sites for the collection of environmental samples (soil, vegetation) and birth products to determine the persistence of *Brucella* in the environment.

Serologic and culture tests were conducted on bison that emigrated beyond the borders of Yellowstone Park and were destroyed. Twenty-six were seropositive. Of these 26, 12 were culture positive.

At the end of 1998, we have 52 radio collared animals, including 13 calves of the year. Samples collected from 22 birth sites during the spring of 1998 were negative for *Brucella*. Data collected from killed bison during the winter of 1996/97 showed a relationship between culture and serology similar to that in chronically infected cattle. Plans for the upcoming year include deployment of more vaginal transmitters to document birth sites and continued sampling of study animals throughout the year. The project has an anticipated completion date of September 2001.

Title: **Wolf Restoration and Population: Monitoring of Wolves in Yellowstone National Park**

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Objectives: Restore wolves to Yellowstone National Park; monitor population dynamics; monitor predator/prey interactions; monitor behavior and denning activities; monitor the impact of wolves on the scavenger complex.

Findings: The total number of wolves is about 112 animals and there are eleven total packs. Forty-three pups were born in 1998. Ninety percent of the wolves' diet consists of elk; other prey species include moose, bison, and mule deer. The kill rate for each of the northern range packs (Leopold, Rose Creek, and Druid Peak) is approximately 150 elk per year.

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